TES observations of tropospheric ozone as a greenhouse gas

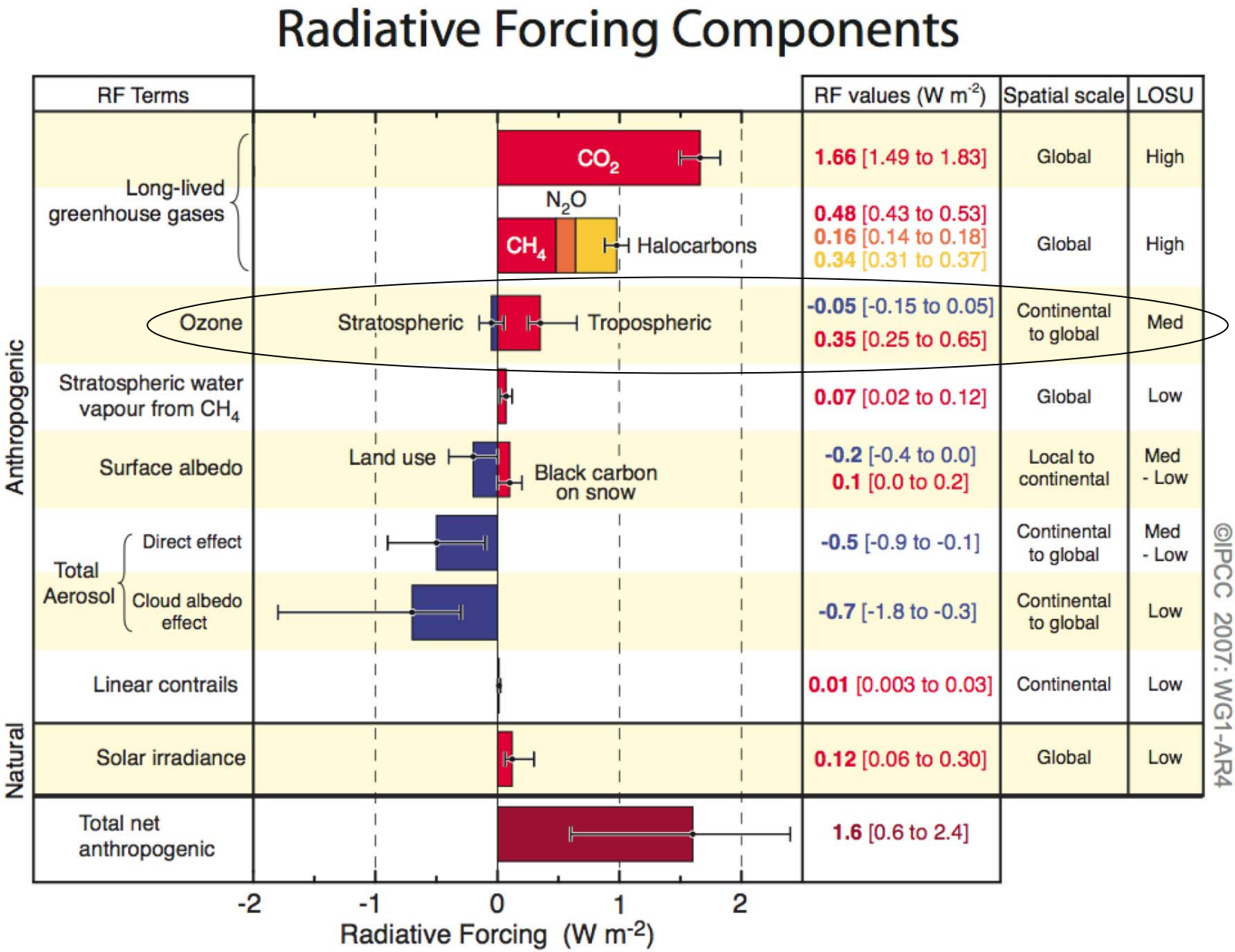
H. Worden*, K. Bowman, J. Worden, A. Eldering, JPL

*now at NCAR

• TES retrieves ozone profiles from spectrally resolved IR radiances.

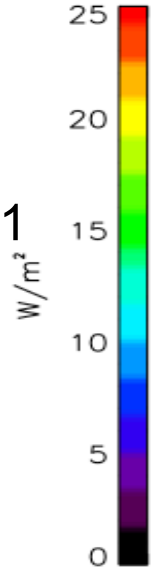
• Using both spectra and retrievals, we can examine the sources of variability in the outgoing flux for the IR ozone absorption band.

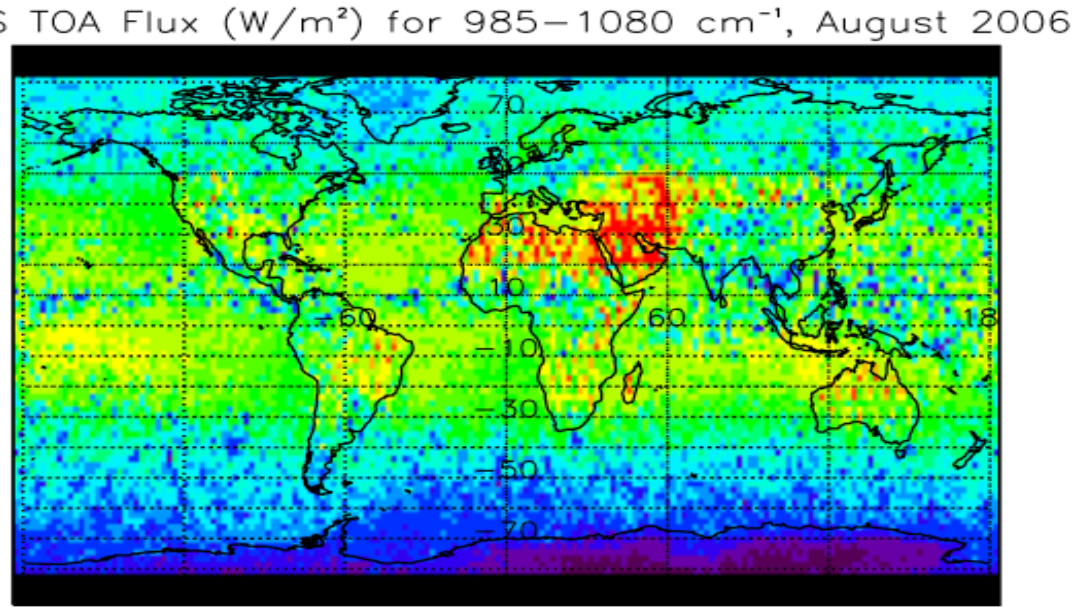
4th IPCC Assessment (2007)



TES

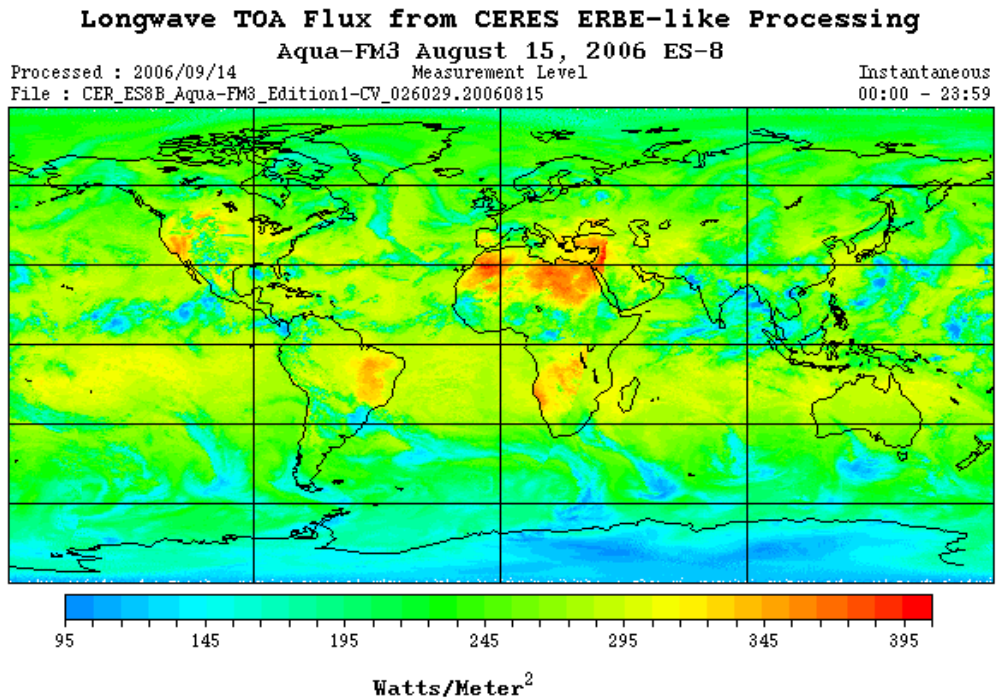
TOA flux for 985-1080 cm^{-1} Aug 2006 (W/m^2)



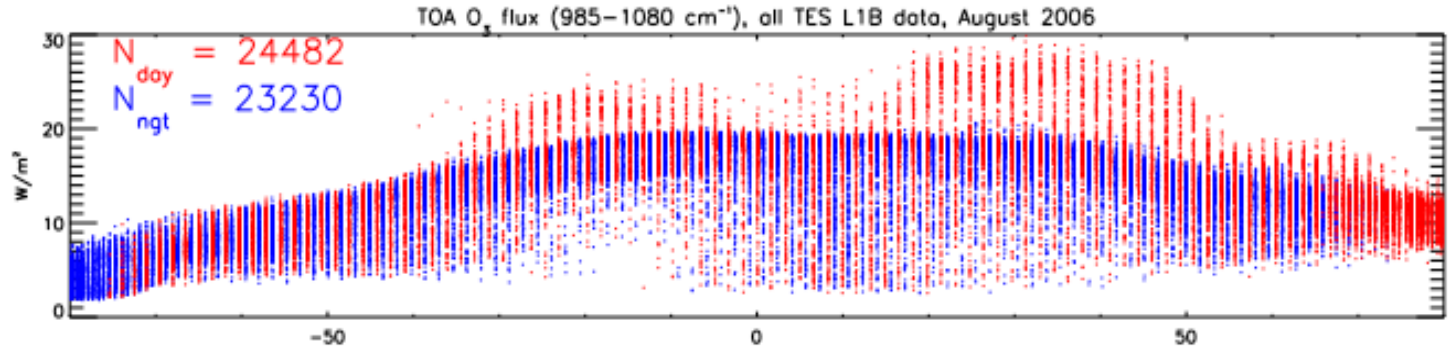


CERES

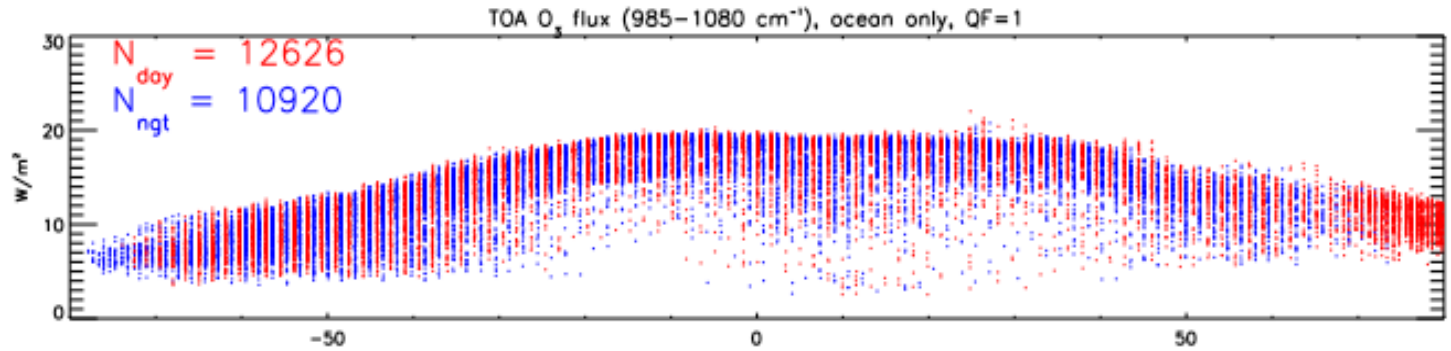
Longwave TOA flux Aug 15, 2006 (W/m^2)



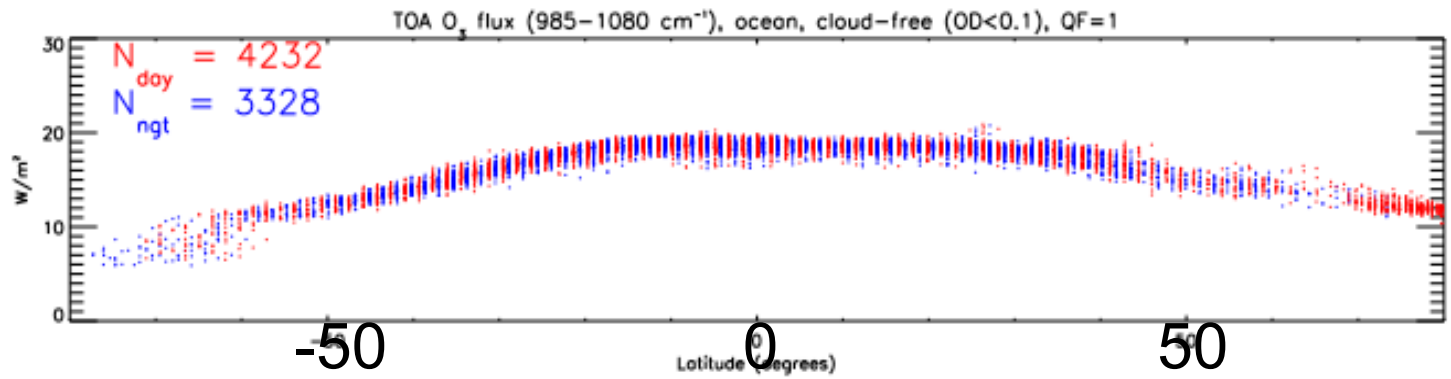
TES TOA flux (985-1080 cm^{-1}) Aug 2006



All spectra



Ocean only
QF=1

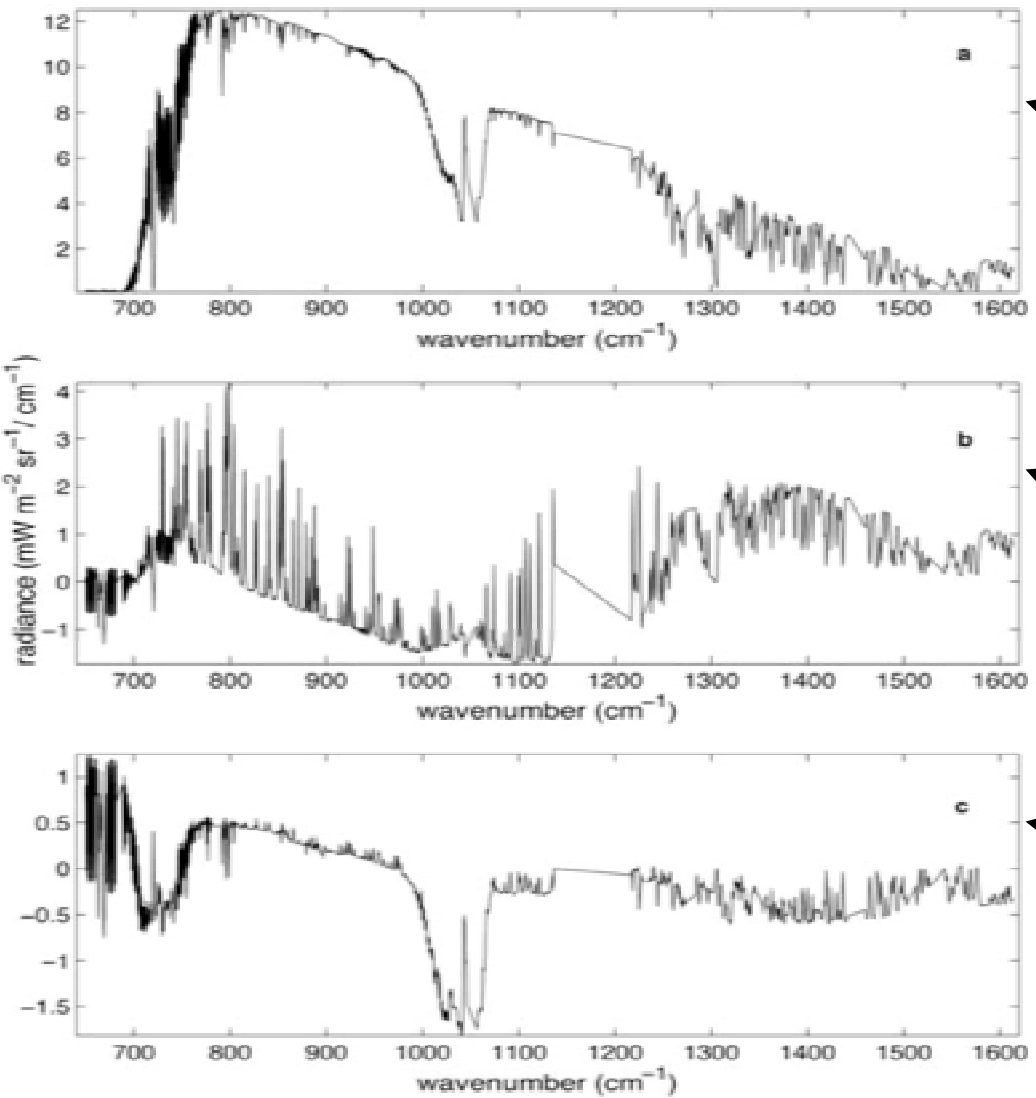


Ocean only
QF=1
Cloud-free

W/m^2

Latitude (degrees)

AIRS nadir spectra principal component analysis



Huang & Yung, 2005

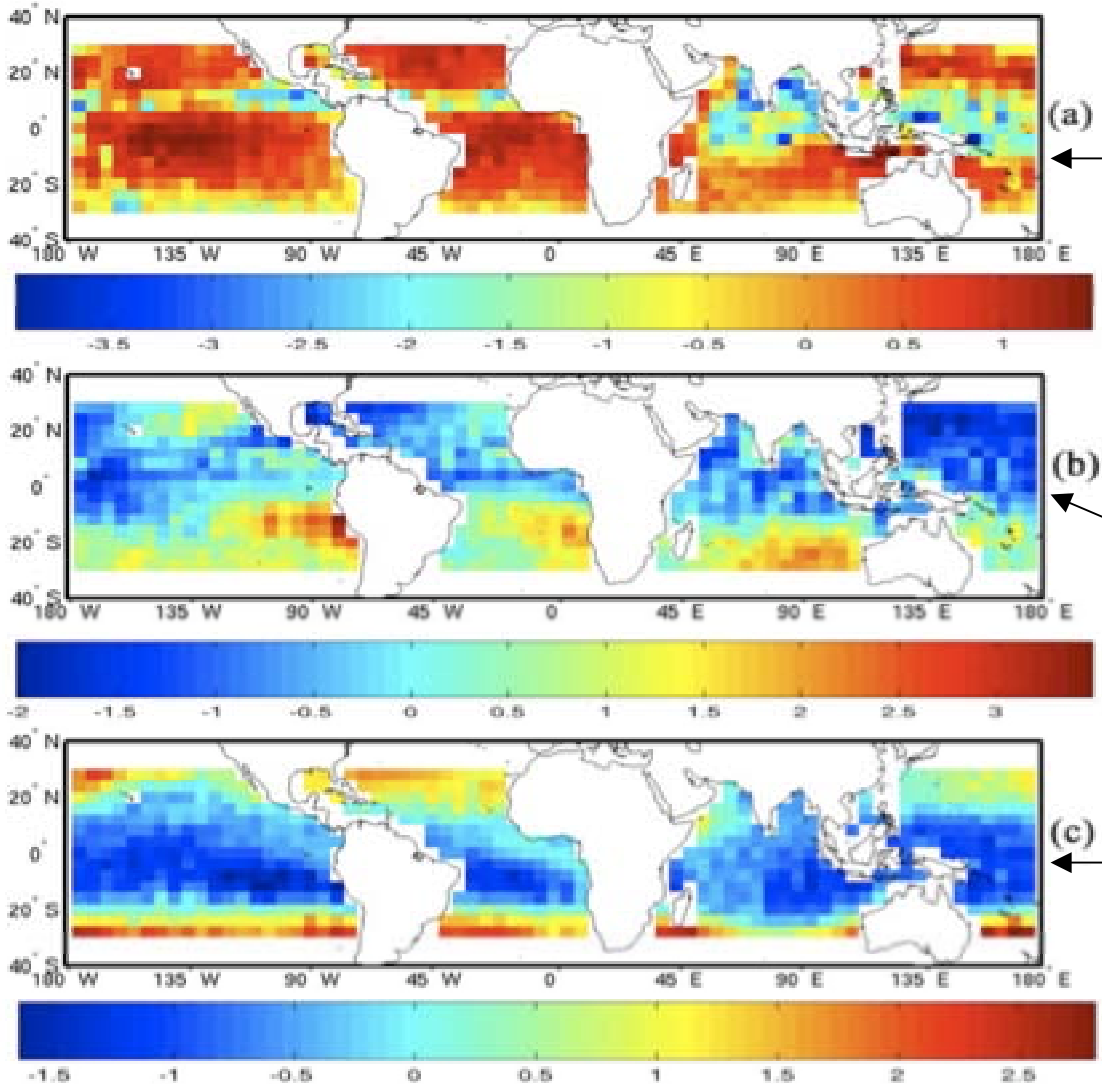
PC1: surface vs. cloud top thermal contrast

PC2: low clouds and LT water vapor

PC3: tropopause

Figure 3. (a) The PC1 over the tropical/subtropical oceans between 32°S and 32°N derived from AIRS spectra collected during July 1–16, 2003. (b) The PC2. (c) The PC3.

AIRS nadir spectra principal component analysis



Huang & Yung, 2005

PC1: surface vs. cloud top thermal contrast

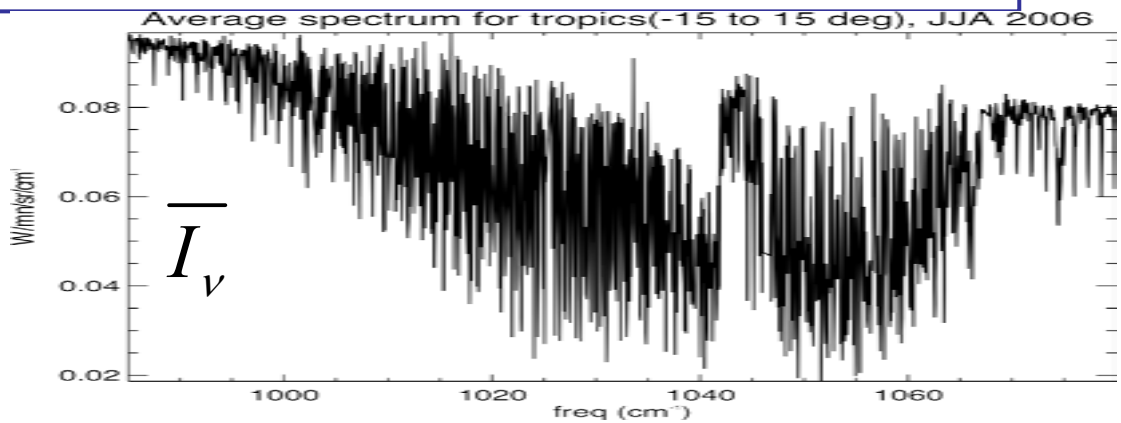
PC2: low clouds and LT water vapor

PC3: tropopause

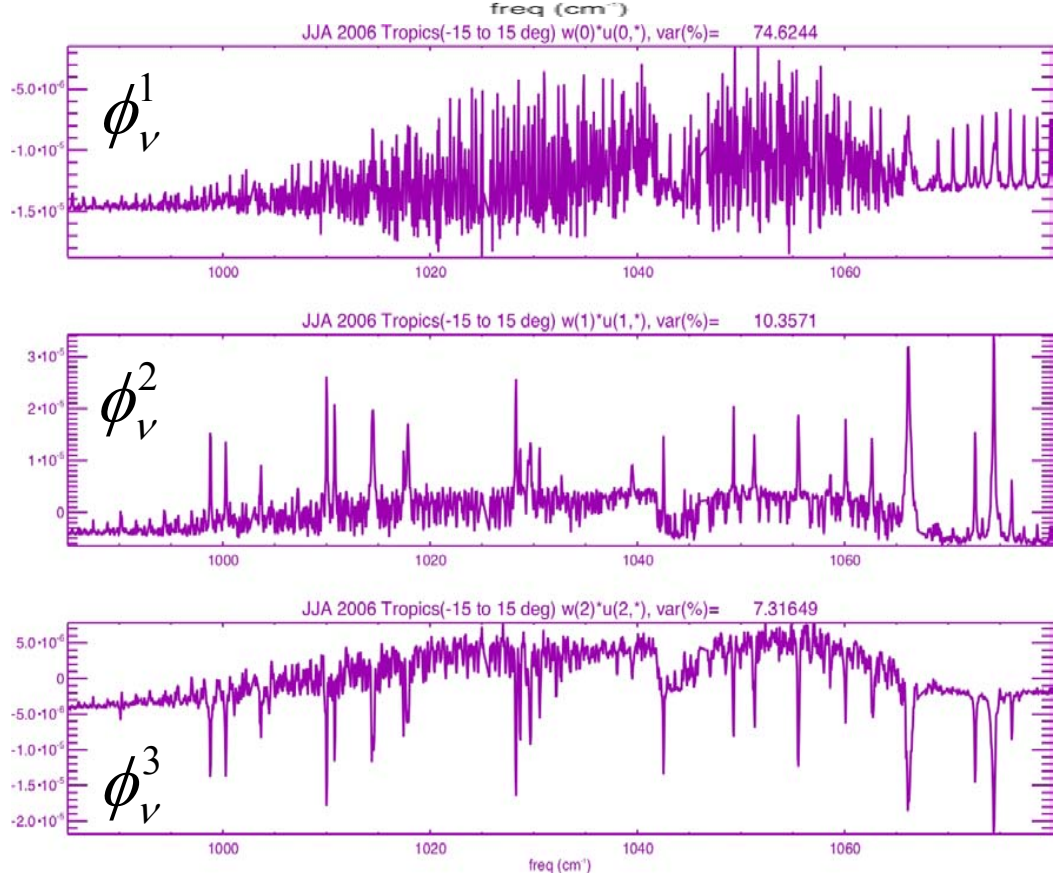
Figure 4. (a) The spatial map of the PC1 shown in Figure 3a. In other words, it is the normalized expansion coefficient of the PC1 computed based on equation (3) in the context. (b) The spatial map of the PC2 shown in Figure 3b. (c) The spatial map of the PC3 shown in Figure 3c.

SVD for cloud-free, ocean, tropics TES spectra

Average radiance
JJA 2006 tropics
985-1080 cm^{-1}



1st 3 Singular Vectors
(93.7% of variance)



Primary variability from:

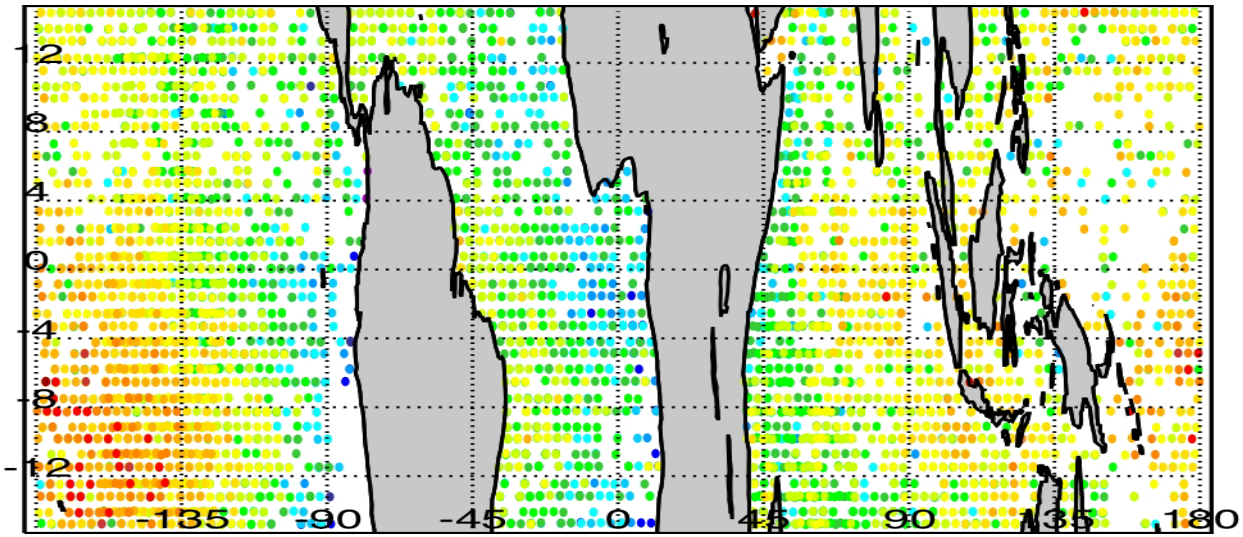
- ϕ_ν^1 SST
- ϕ_ν^2 water vapor
- ϕ_ν^3 upper trop. O3

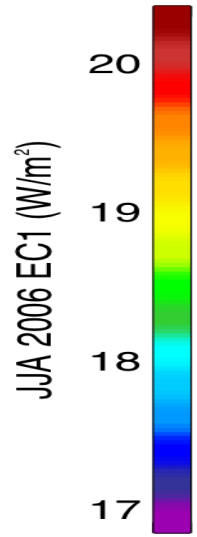
Maps of integrated expansion coefficients:

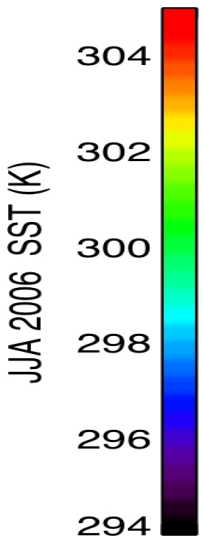
$$EC_i(x) = \int_{\nu} \left[\left\langle [I_\nu(x) - \overline{I}_\nu], \phi_\nu^{(i)} \right\rangle \phi_\nu^{(i)} + \overline{I}_\nu \right] d\nu$$

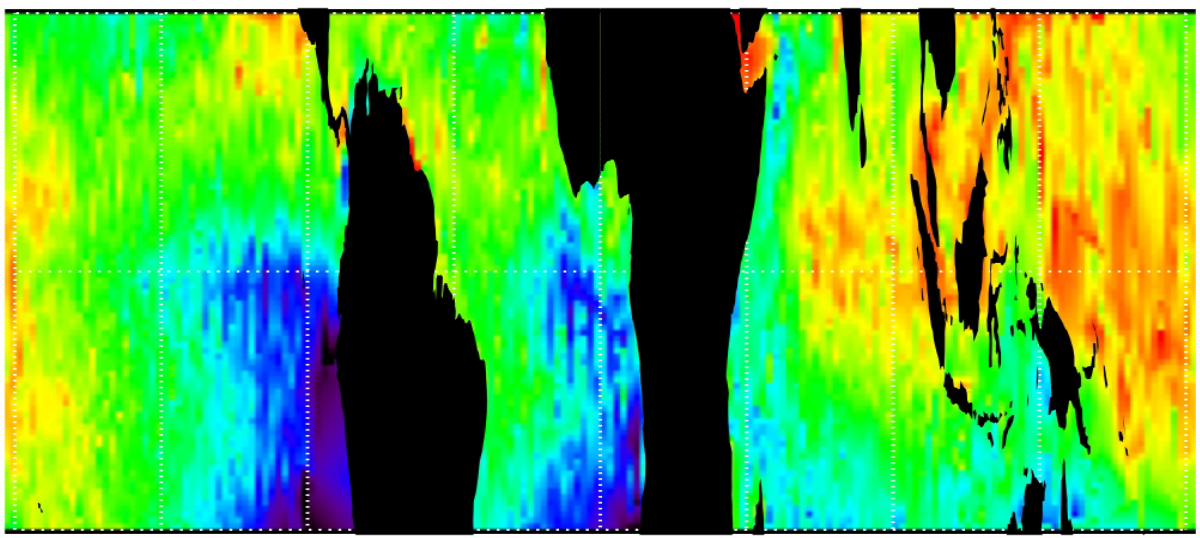
EC1 =

Coeffs. for 1st SV in W/m²



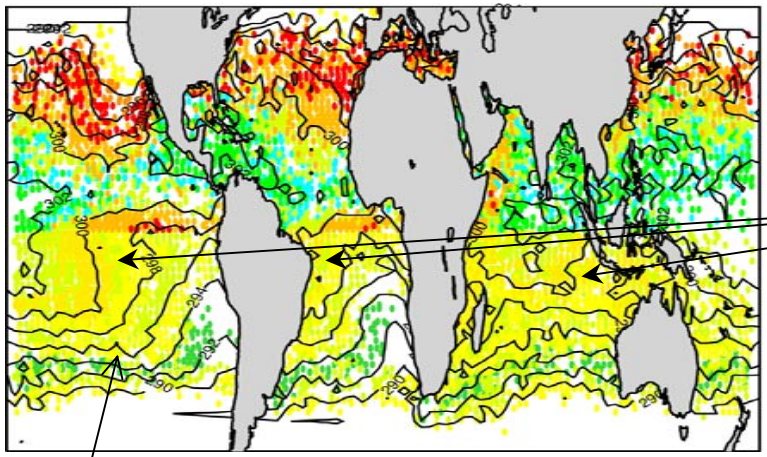


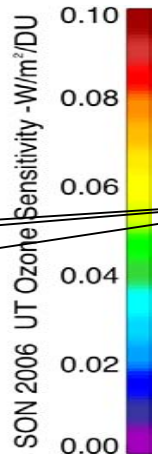




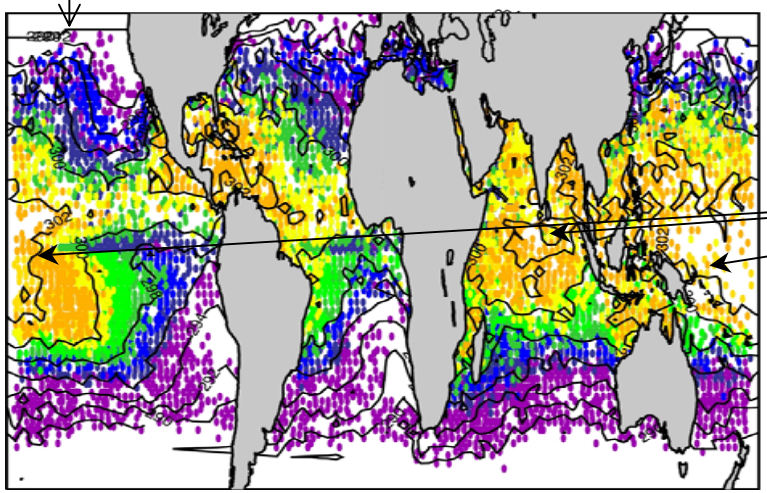
SST (K) JJA 2006

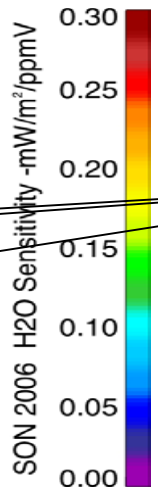
Linear fits of TOA flux (W/m^2) vs ozone and water vapor N/S hemisphere SST bin ensembles, SON 2006

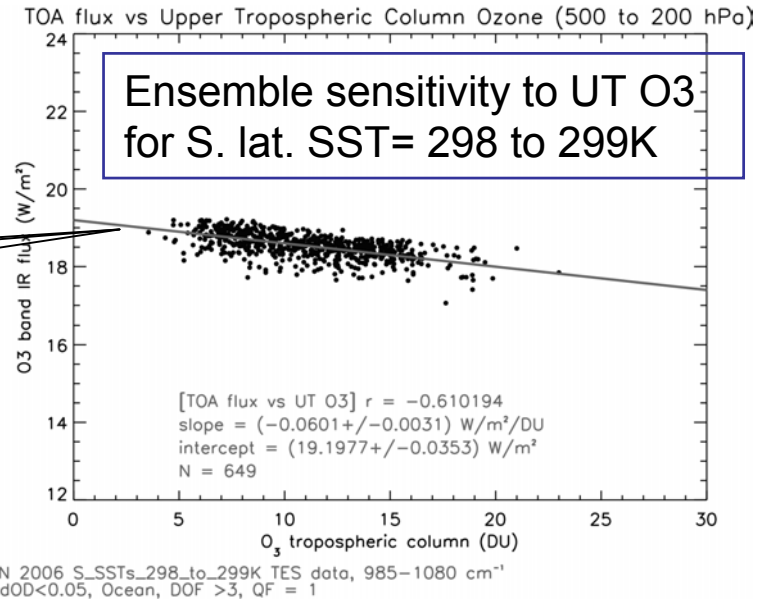


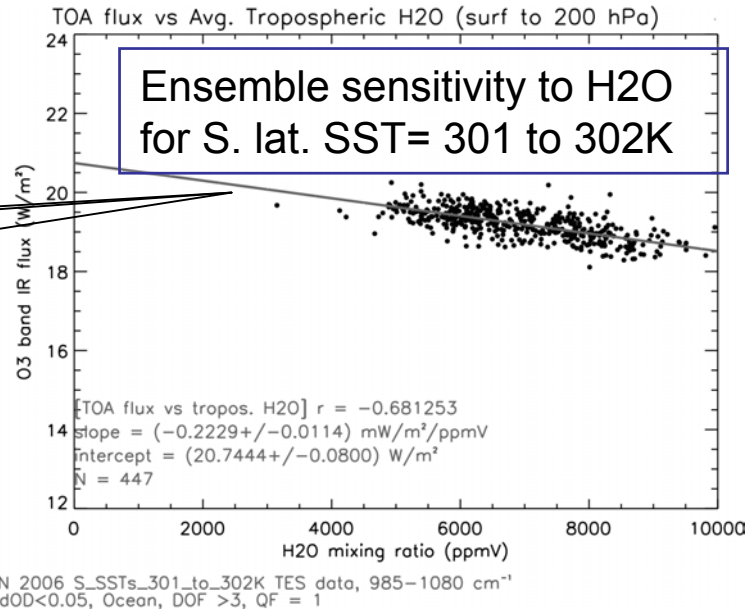


Contours are 2K in SST





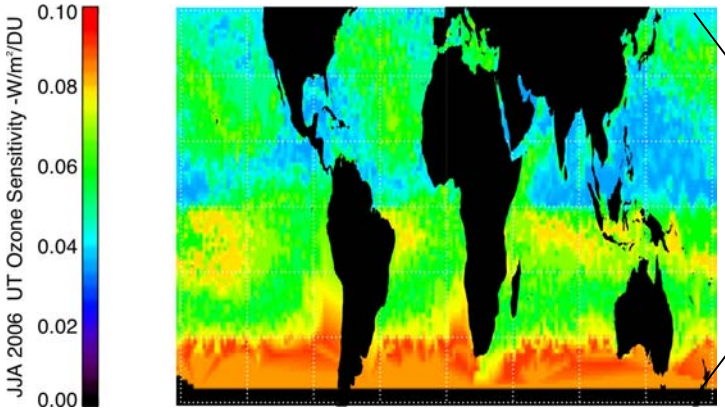




Normalized Radiative Forcing (W/m^2/DU)

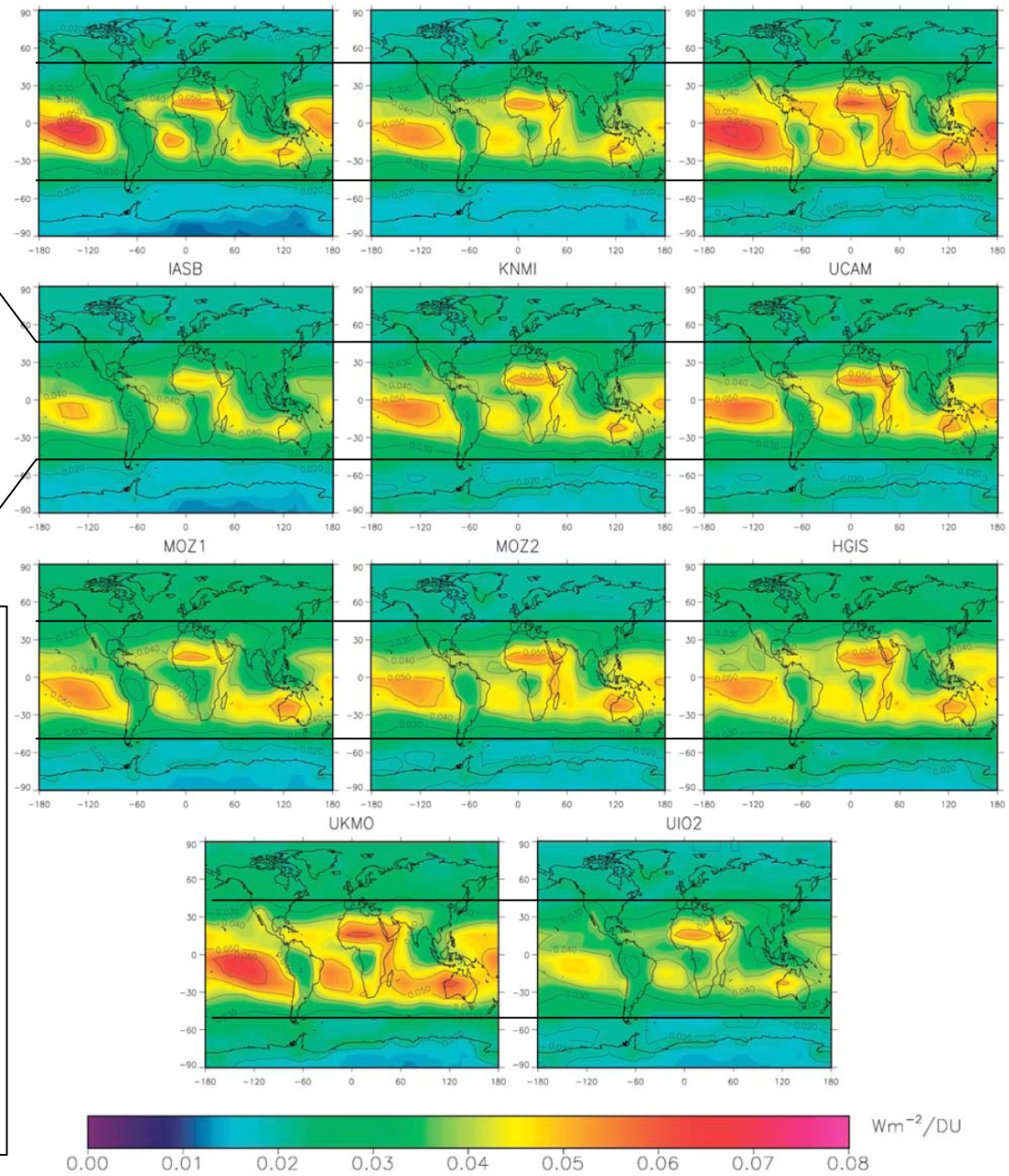
Gauss et al., JGR, 2003, Radiative Forcing in 21st Century due to ozone changes in troposphere/lower strat.

TES JJA 2006 ensemble sensitivities

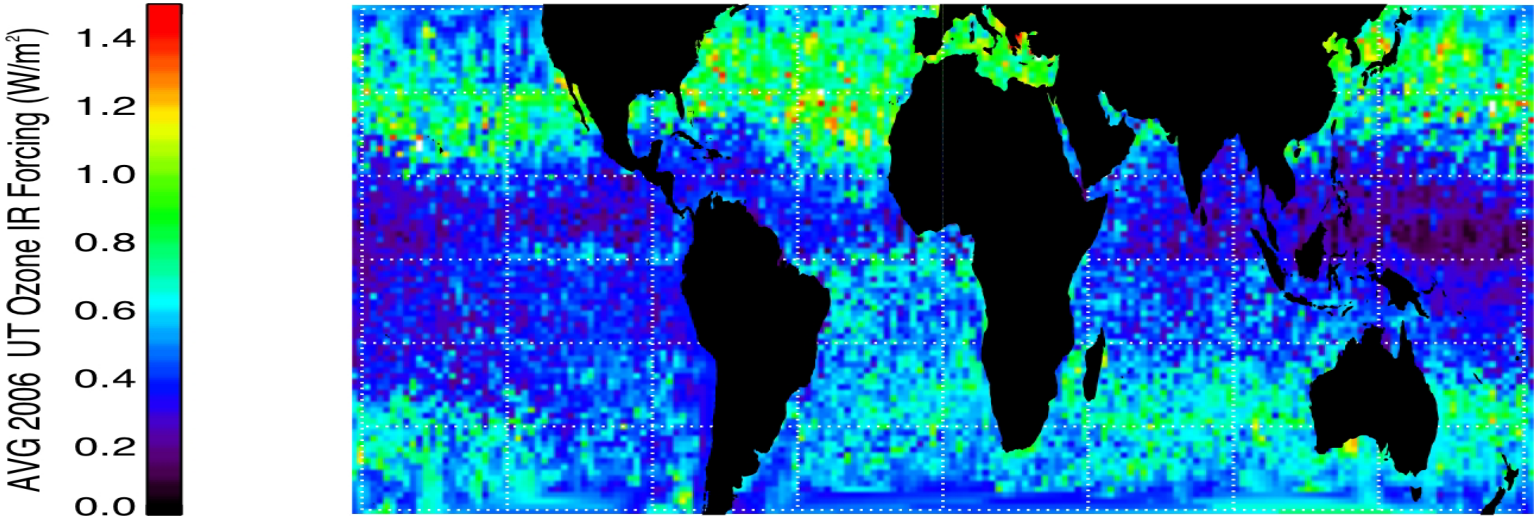


TES global, annual (45°S to 45°N) TOA avg.
= 0.055 W/m^2/DU
(0.017 st.dev.)

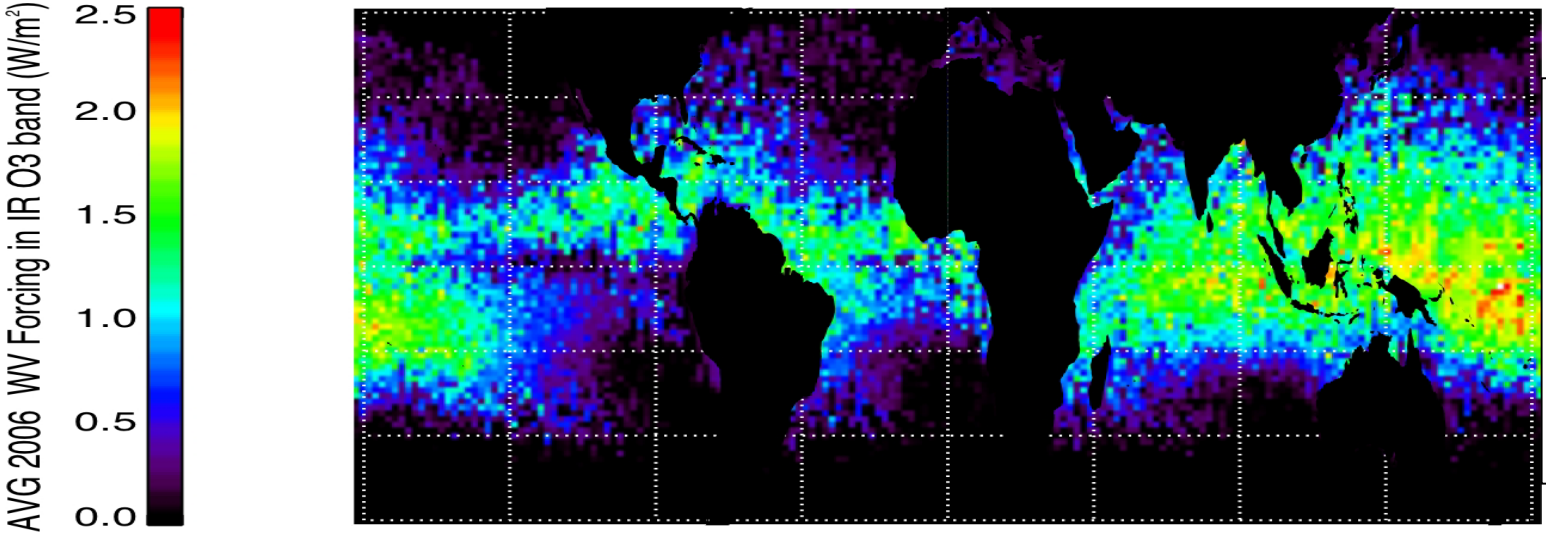
Model range
= 0.042 - 0.052 W/m^2/DU
LW clear, inst., all lats, trop only (no strat)



OLR reduction due to upper tropospheric ozone

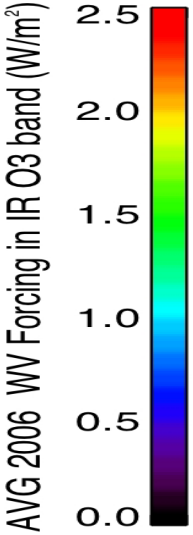


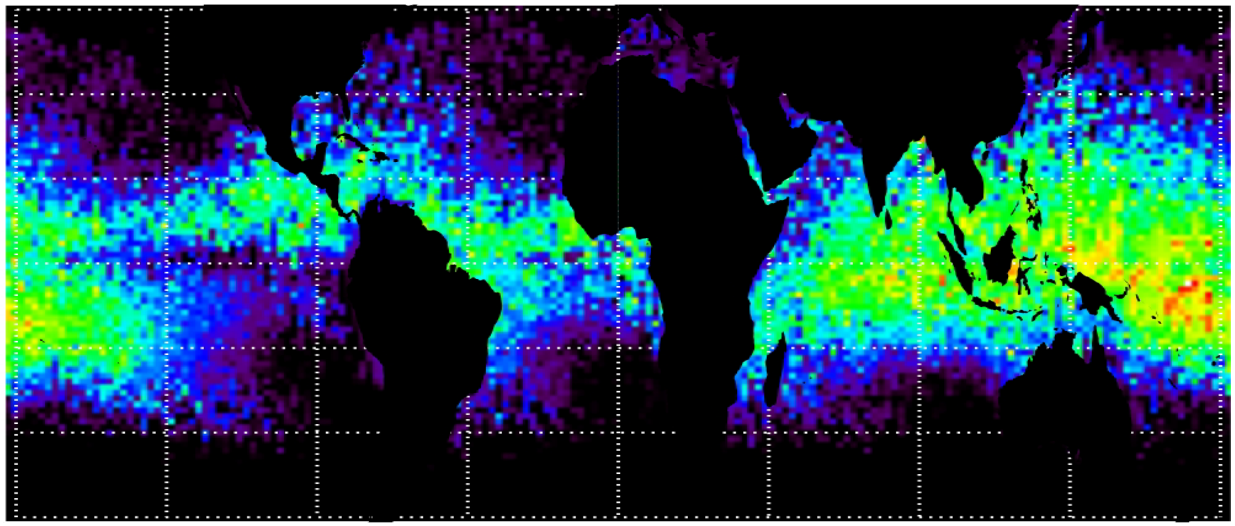
TES global, annual avg = 0.48 W/m^2 (0.24 std) for 45°S to 45°N
IPCC (2007) value for anthropogenic tropospheric ozone radiative forcing = 0.35 W/m^2 (range = 0.25 - 0.65)



Reduced OLR from water vapor absorption in IR ozone band

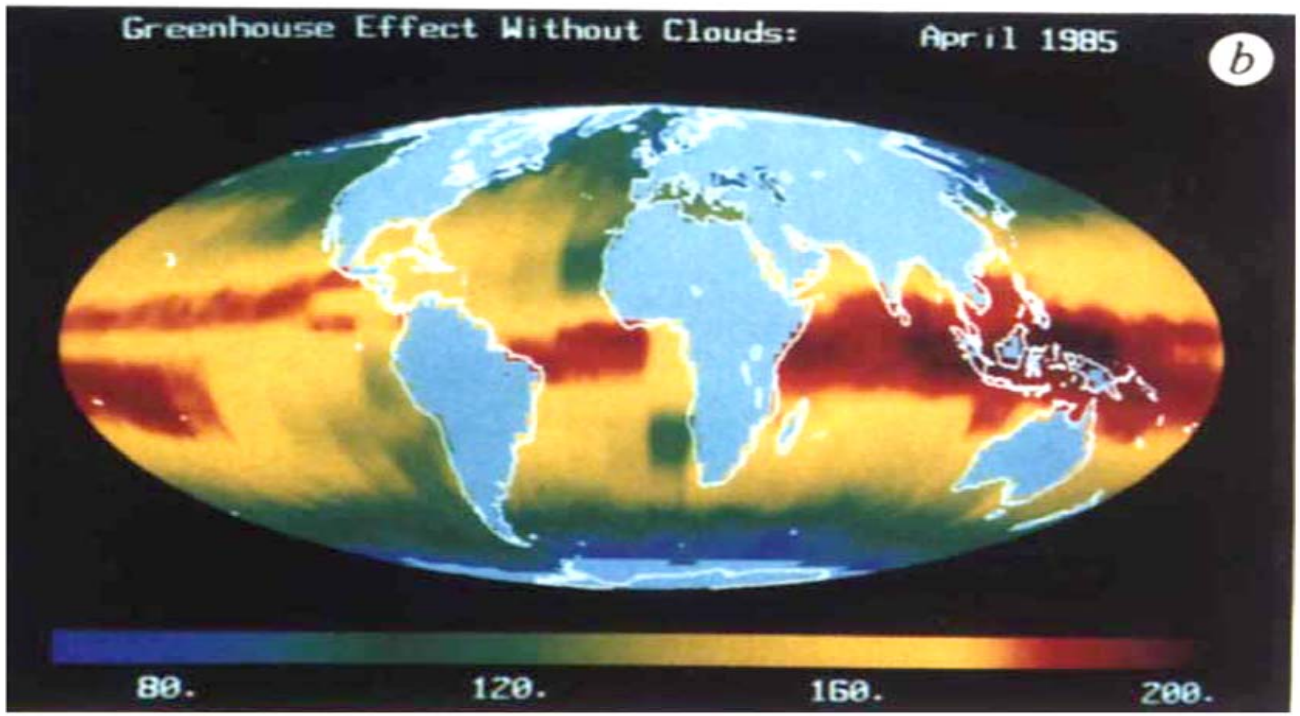
Reduced OLR from water vapor in IR ozone band





Greenhouse Effect (W/m^2)

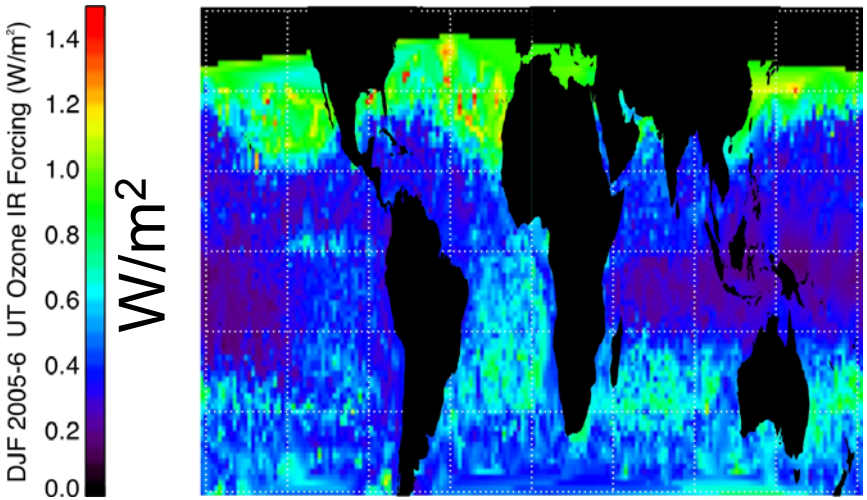
$$G = \sigma T^4 - F_{TOA}$$



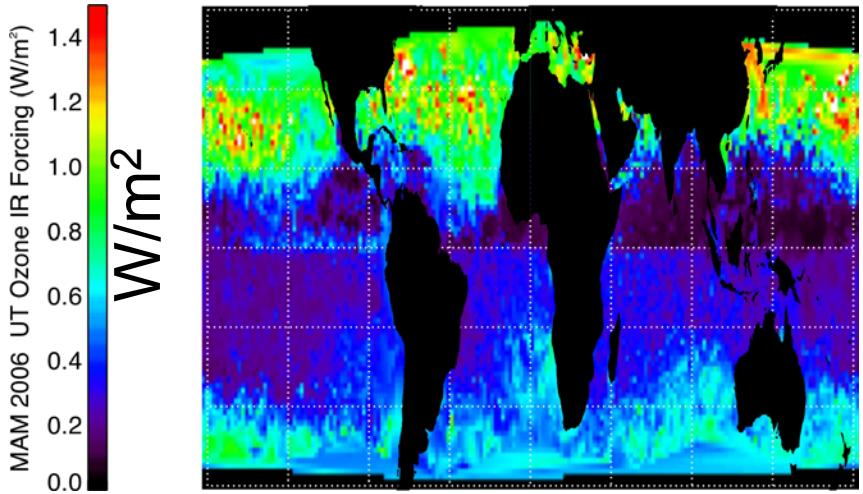
A. Ravel & V. Ramanathan, *Nature*, 1989

Seasonal dependence of UT ozone OLR reduction

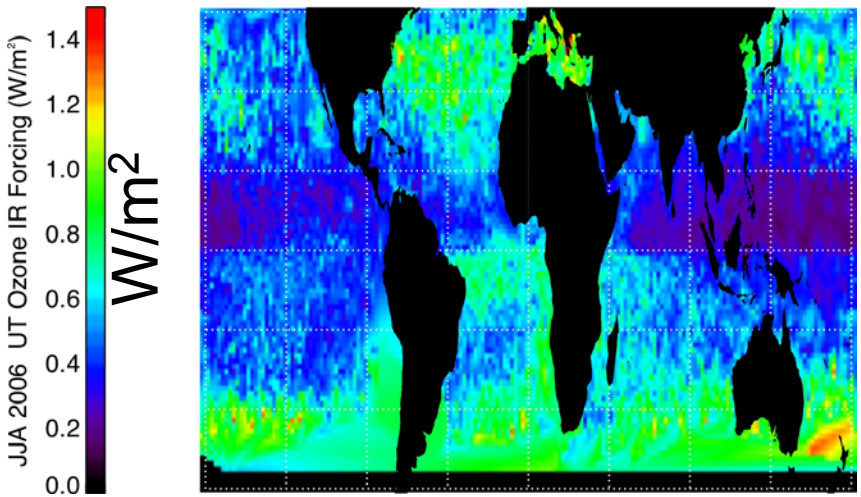
DJF 2005-2006



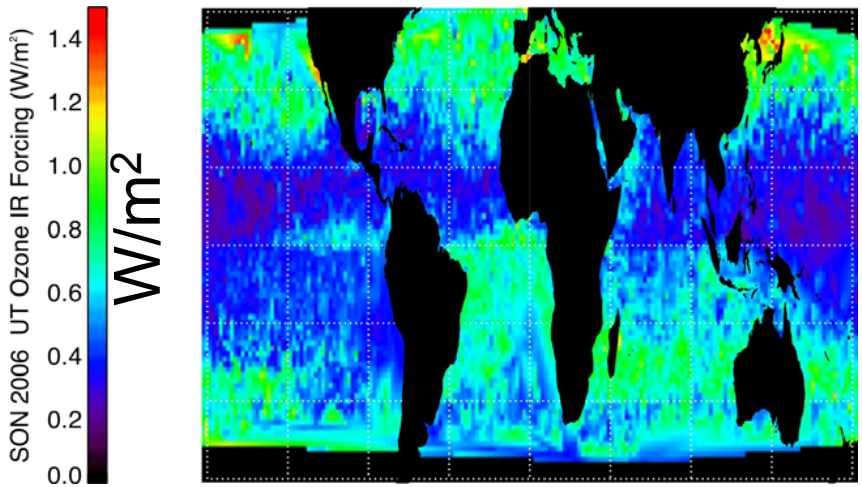
MAM 2006



JJA 2006

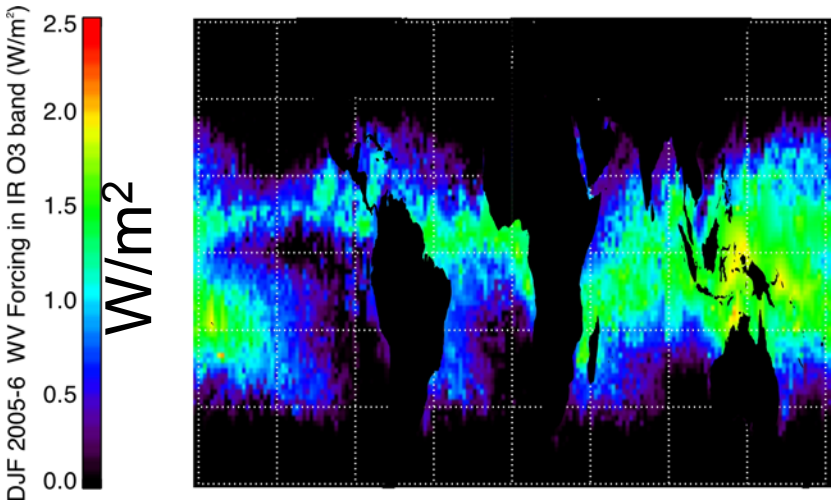


SON 2006

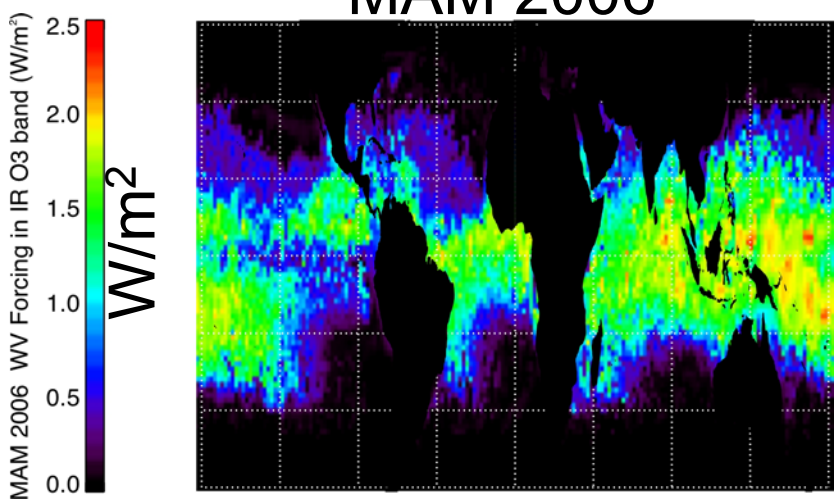


Seasonal dependence of OLR reduction due to water vapor in IR ozone band

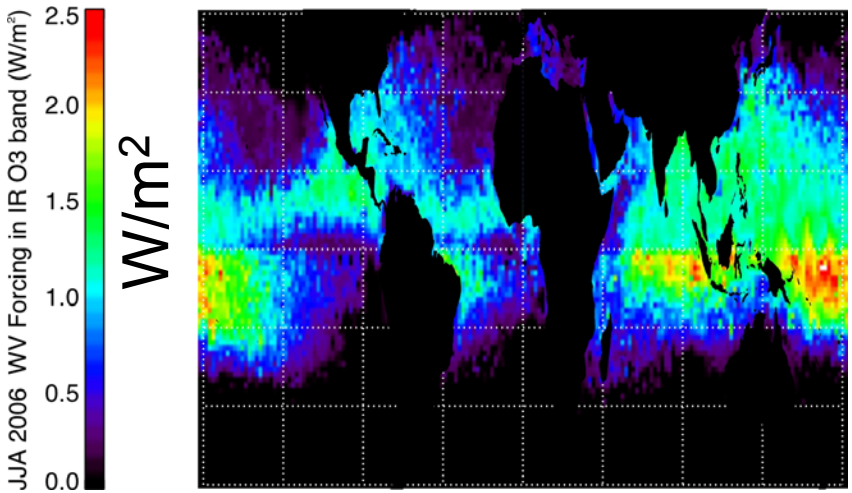
DJF 2005-2006



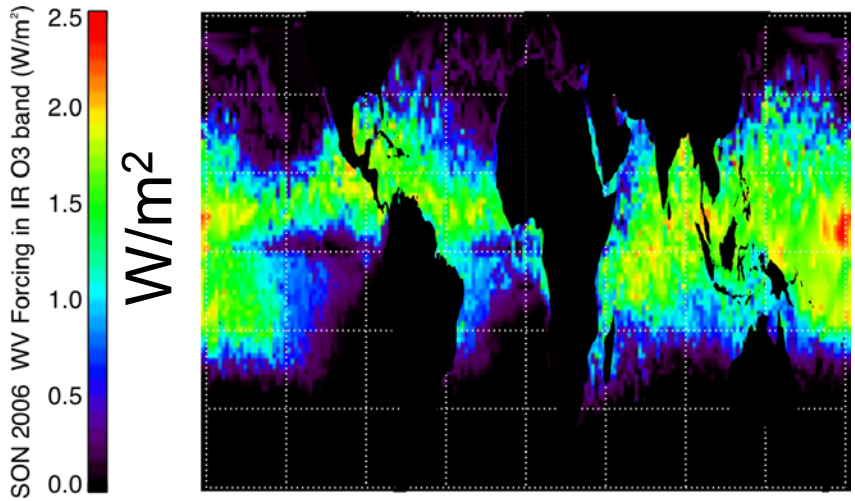
MAM 2006



JJA 2006



SON 2006



Conclusions for OLR sensitivity to tropospheric ozone

- Using TES spectra, retrieved surface & cloud properties and atmospheric profiles, we can investigate the processes that drive OLR variability.
- We estimate OLR sensitivity to ozone and water vapor by constructing ensemble observations binned by SST. We find an annual average OLR sensitivity to upper trop. ozone of 0.055 W/m^2/DU (stdev = 0.017). This is comparable to model estimates but with more sensitivity in the northern hemisphere.
- Using estimated sensitivities, we find the average OLR reduction = 0.48 W/m^2 (stdev = 0.24 std) for upper trop. ozone (global, annual avg., -45⌖ to 45⌖)
  - IPCC (2007) value = 0.35 W/m^2 (range = 0.25 - 0.65) for anthropogenic trop. ozone

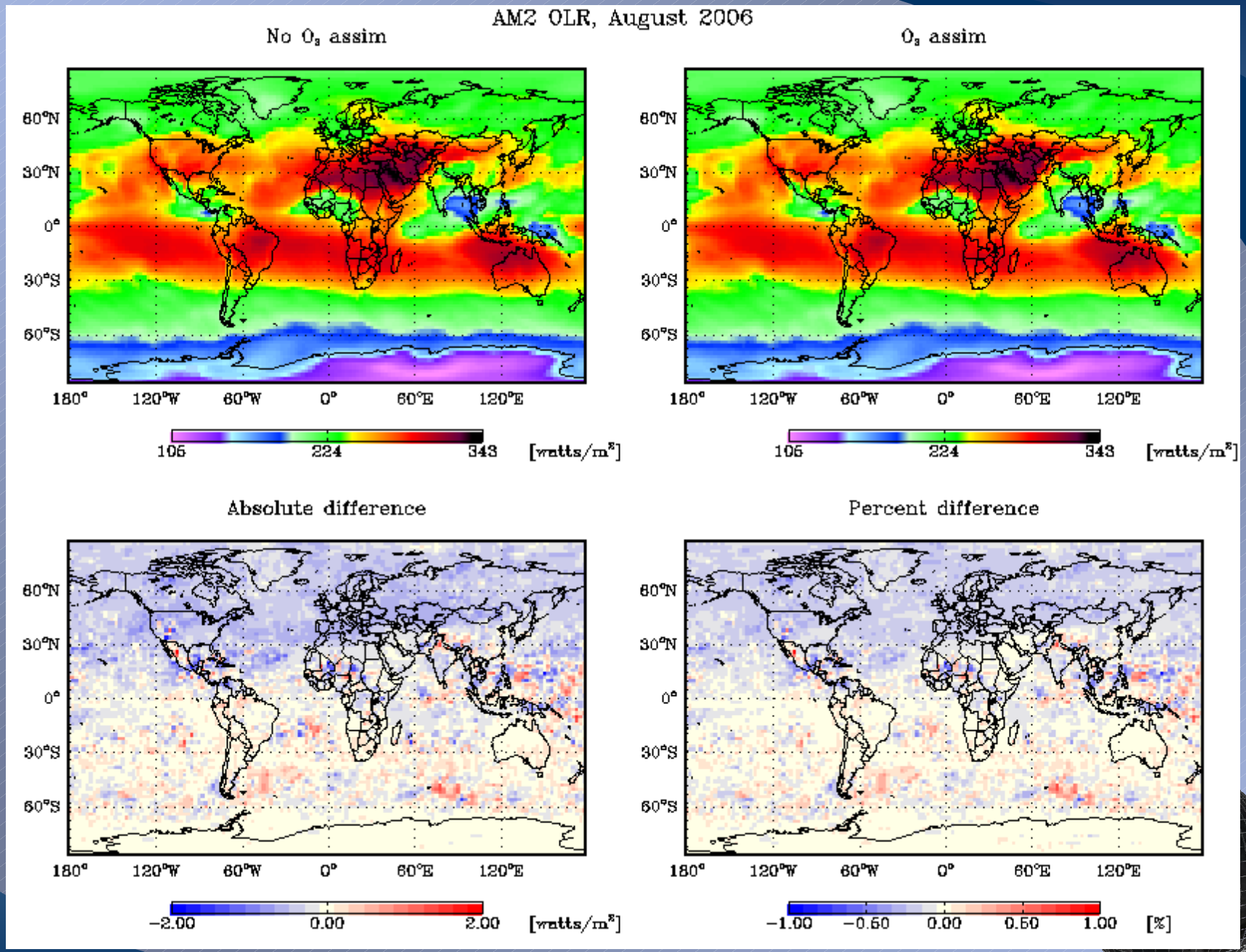
Future directions

- Using TES observations of OLR and ozone to test the processes that drive OLR variability in climate models.

- Investigate OLR sensitivity for other atmospheric species e.g. H_2O, CH_4, CO_2 for any observation altitude/lat/lon.
  -based on computed jacobians

- Characterize OLR sensitivity for different surface & cloud conditions

- Separate anthropogenic and natural contributions using inverse modeling



M. Parrington & D. Jones, U. Toronto

Radiance-to-Flux Conversion

$M = \pi L / R(\theta)$

With M = flux estimate in W/m^2
L = radiance in W/m^2/sr
$R(\theta)$ = anisotropy from an angular dist. model (ADM).
For LW, R depends on the viewing angle, θ.
(from ERBE references)
For now, using R=1.05 for nadir ($\theta = 0$)

Could use season/latitude/srfc values for R from CERES - range ~ 1.03 to 1.06

1

ANCILLARY INPUT DATA: SEASONAL LW MODELS

DATA FILE : BIILWSM.19980130

SEASON : SUMMER

1

AMATRX

SCENE IDENTIFICATION MODEL # 1 (OCN)

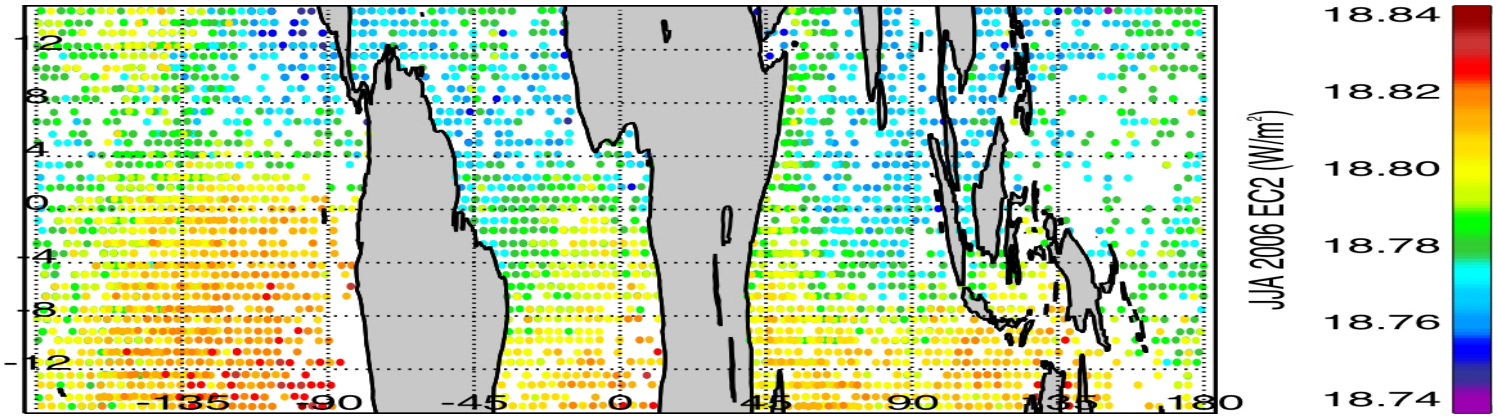
LW ANISOTROPIC MODEL

SPACECRAFT ZENITH BIN NUMBER		COLATITUDINAL BIN #, ANGULAR RANGE									
		1	2	3	4	5	6	7	8	9	10
		[0, 18]	(18, 36]	(36, 54]	(54, 72]	(72, 90]	(90,108]	(108,126]	(126,144]	(144,162]	(162,180]
1	[0,15]	1.036133	1.036133	1.043457	1.043945	1.043457	1.043457	1.040039	1.043945	1.041016	1.041016
2	(15,27]	1.036133	1.036133	1.038574	1.041016	1.041504	1.040527	1.038086	1.036621	1.036621	1.036621
3	(27,39]	1.023438	1.023438	1.025879	1.031250	1.031250	1.029297	1.026367	1.025391	1.022949	1.022949
4	(39,51]	1.009277	1.009277	1.010254	1.011719	1.012207	1.010742	1.009766	1.010742	1.006348	1.006348
5	(51,63]	0.989258	0.989258	0.989258	0.988281	0.989746	0.989746	0.991211	0.991211	0.995605	0.995605
6	(63,75]	0.955078	0.955078	0.947266	0.942383	0.939941	0.943359	0.947754	0.947754	0.952637	0.952637
7	(75,90]	0.910645	0.910645	0.903320	0.892578	0.889648	0.895996	0.902344	0.899902	0.901855	0.901855

TES JJA 2006

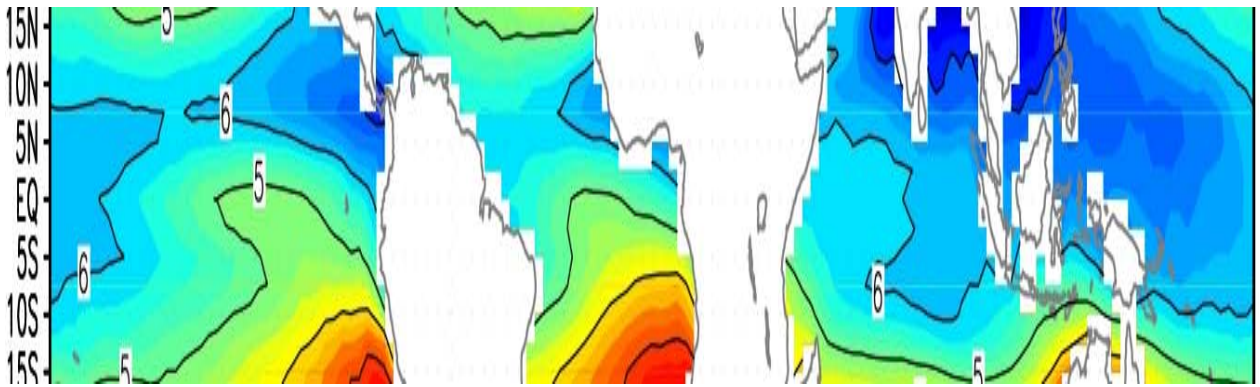
EC2 =

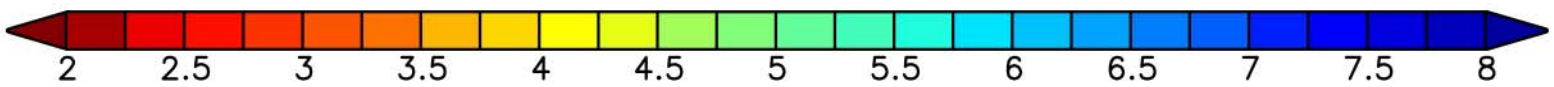
Coeffs for 2nd SV



Highest correlations: H2O (r=-0.68), SST (r=-0.67)

NCEP reanalysis 1000-300 hPa average for specific humidity (g/kg)

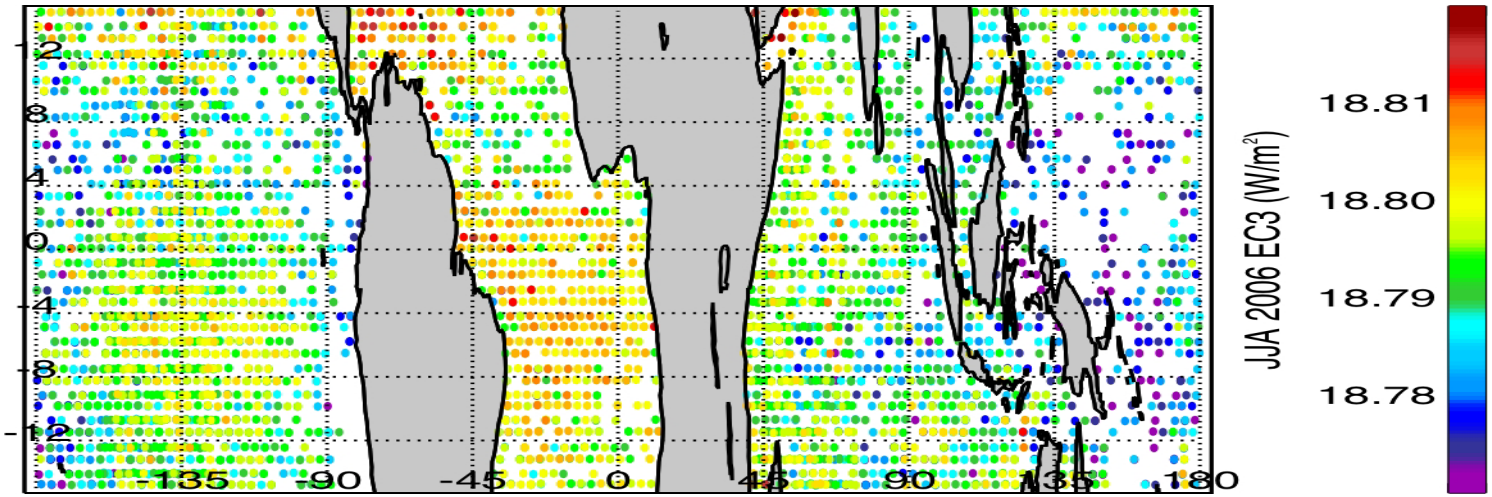




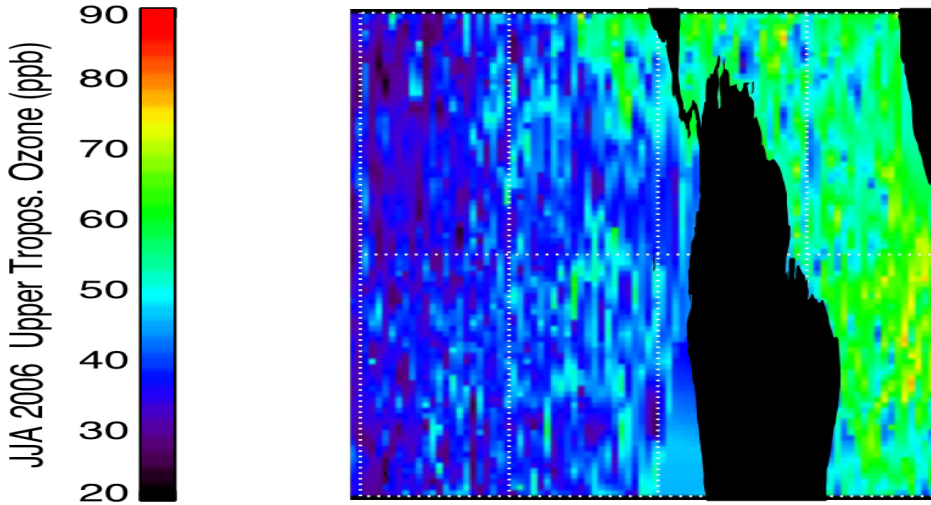
TES JJA 2006

EC3 =

Coeffs for 3rd SV



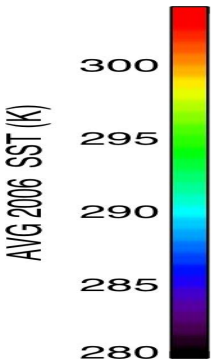
Highest correlation: UT O3 (r=0.60)

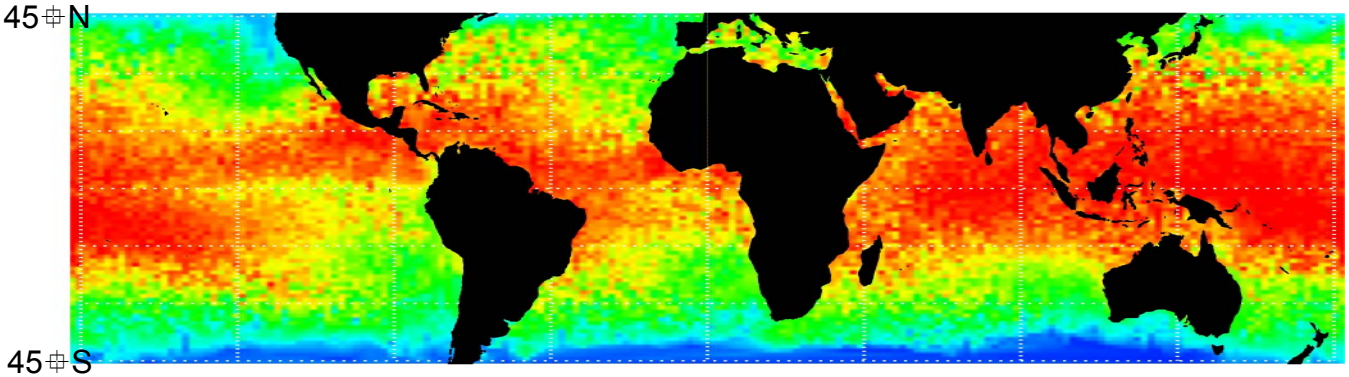


UT O3 (ppb) JJA 2006

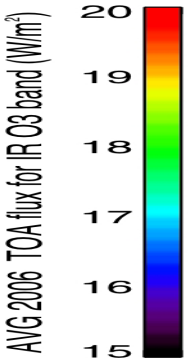
(500-200 hPa)

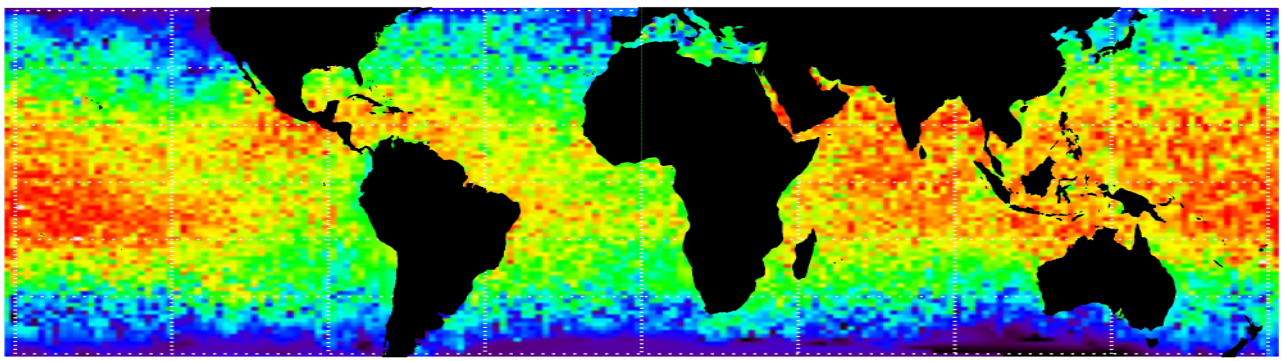
TES 2006 annual averages



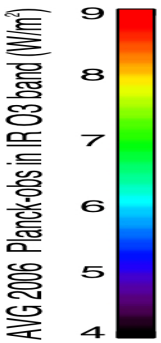


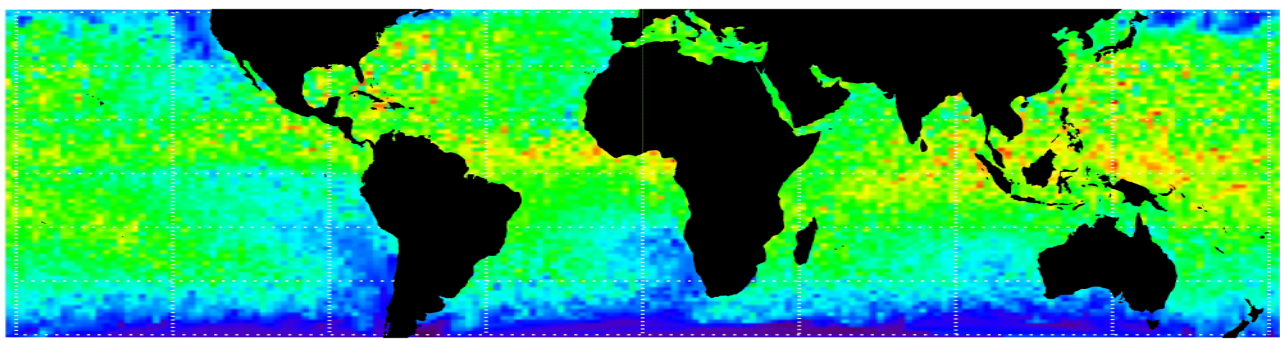
SST





TOA flux for O3 IR band



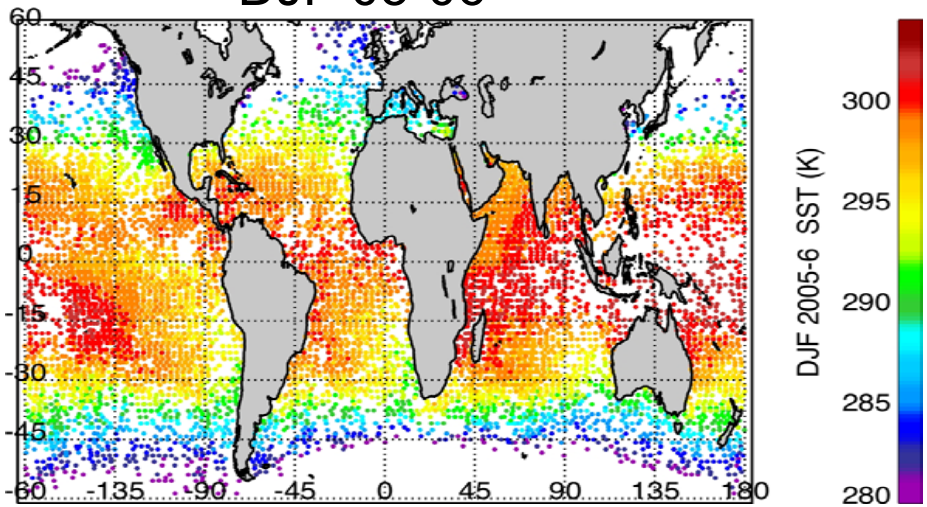


Δflux

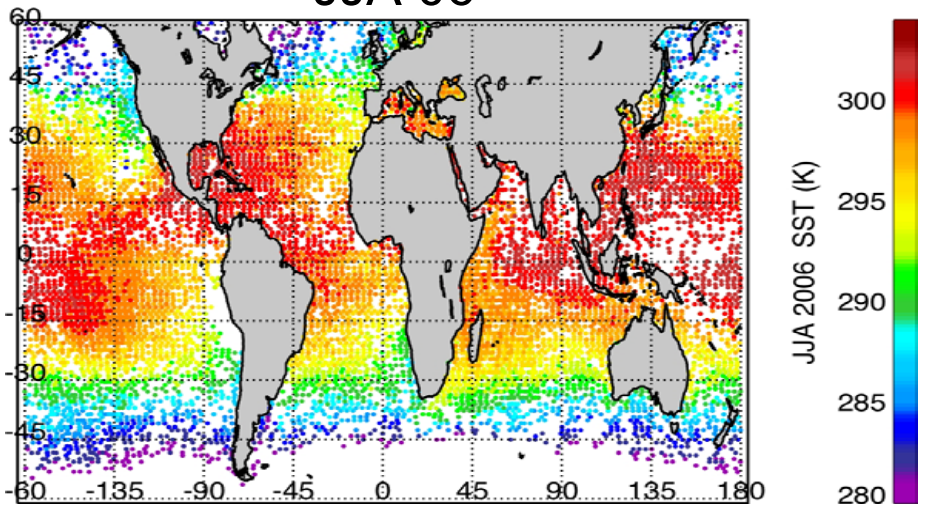
(Planck - obs.)

Sea Surface Temperature (K) - cloud-free ocean scenes

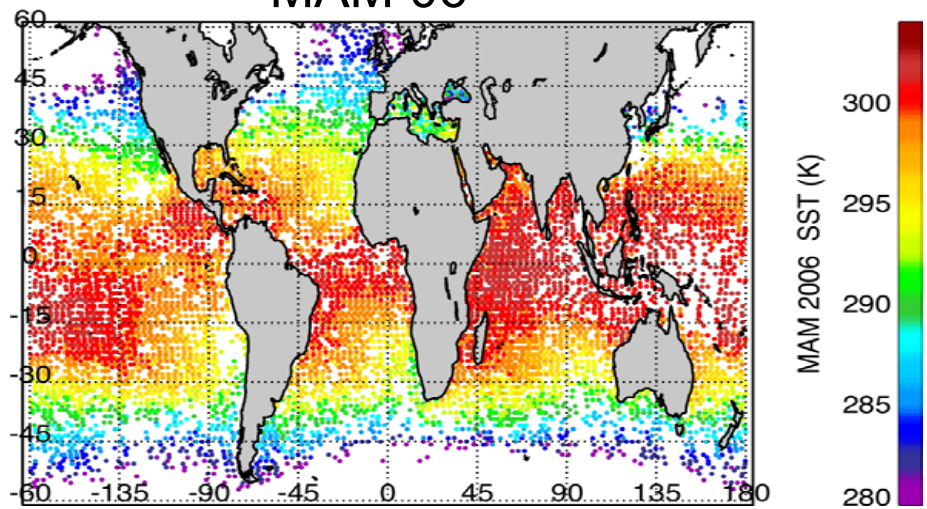
DJF 05-06



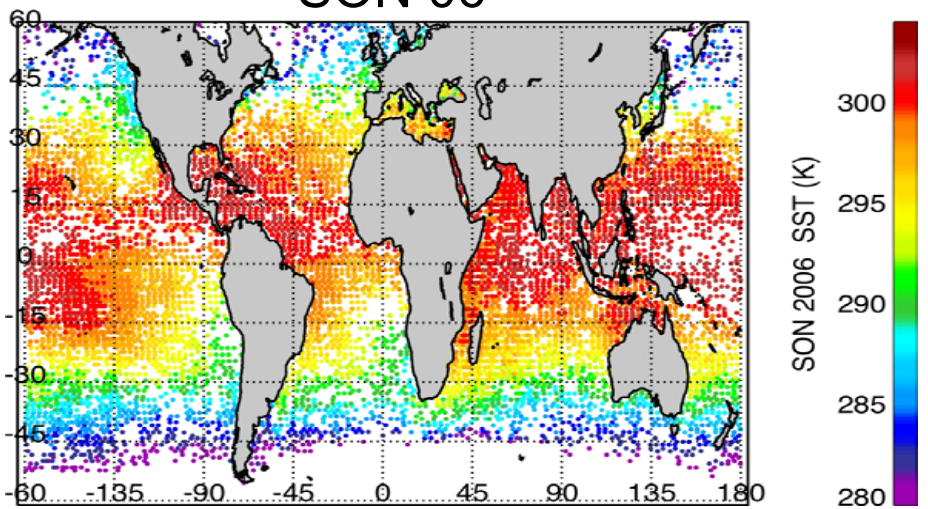
JJA 06



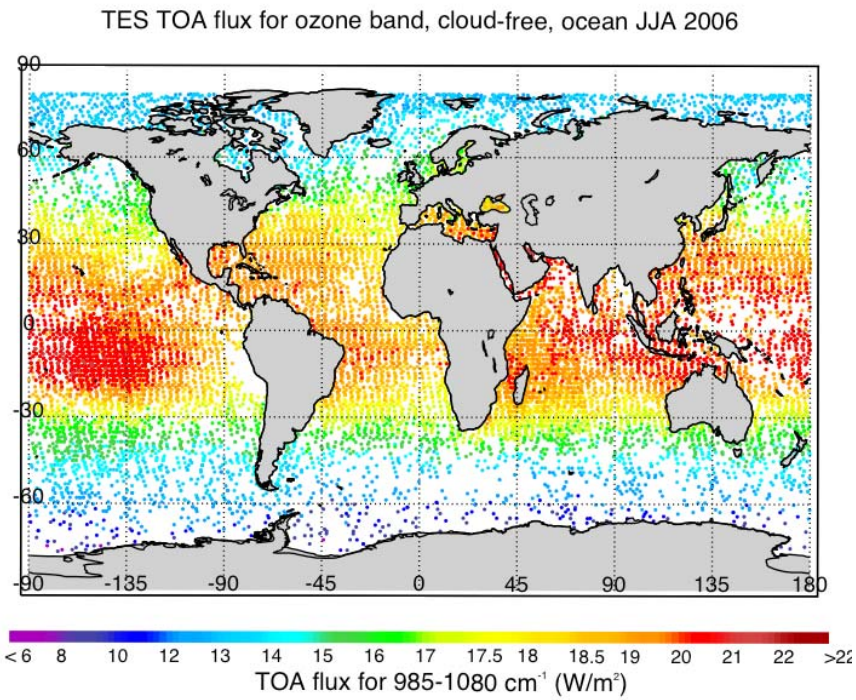
MAM 06

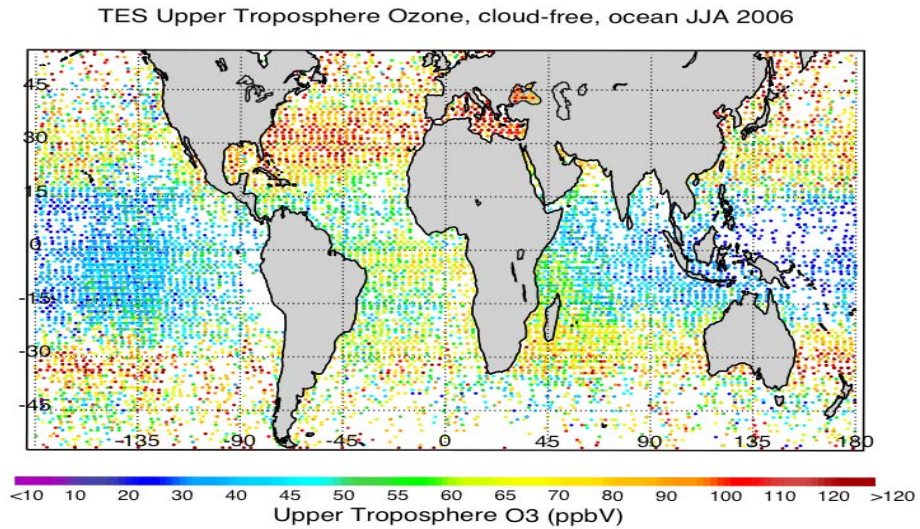


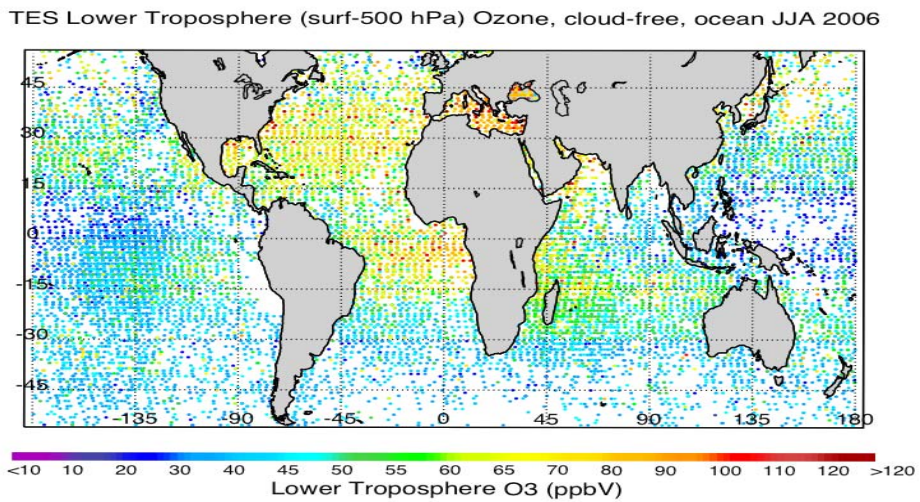
SON 06



TOA flux and ozone for JJA 2006

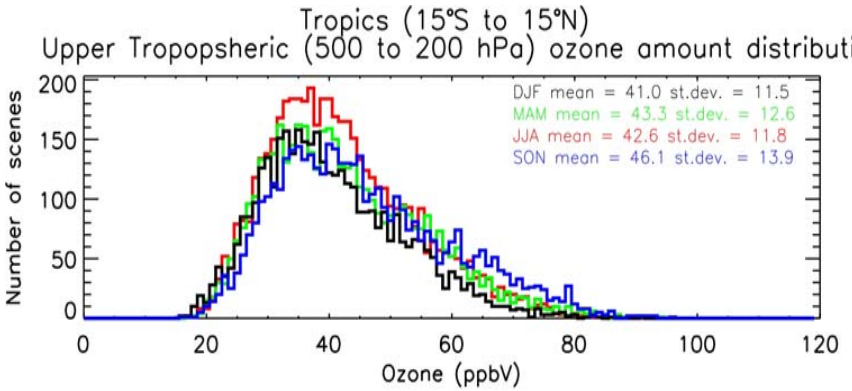


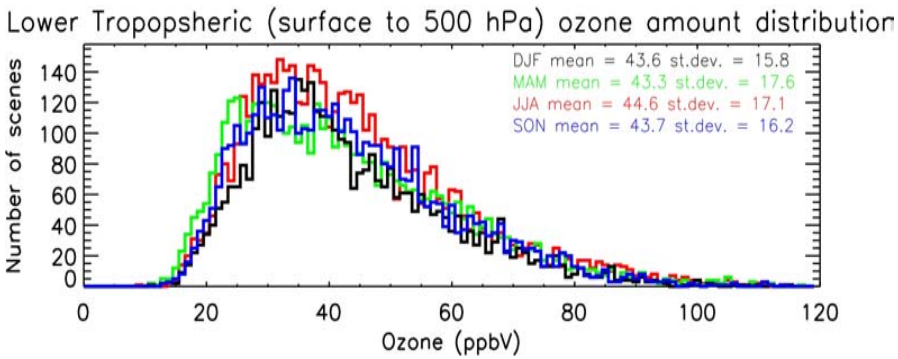




UT = 500-200 hPa for |lat| < 35°
= 500-300 hPa for 35°-55°

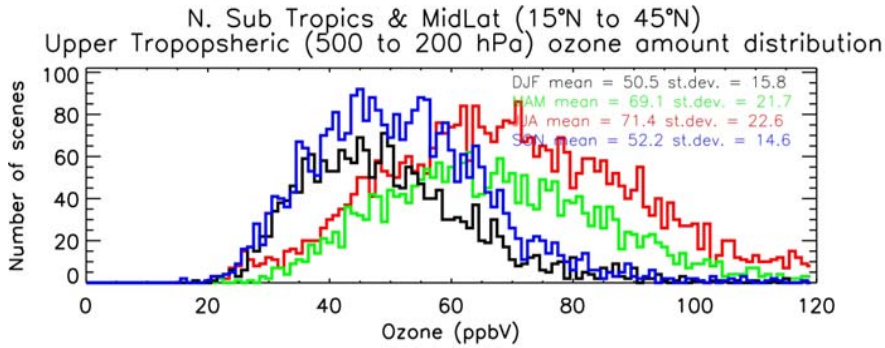
Upper & Lower Troposphere O3 distributions by season, Tropics, N., S.

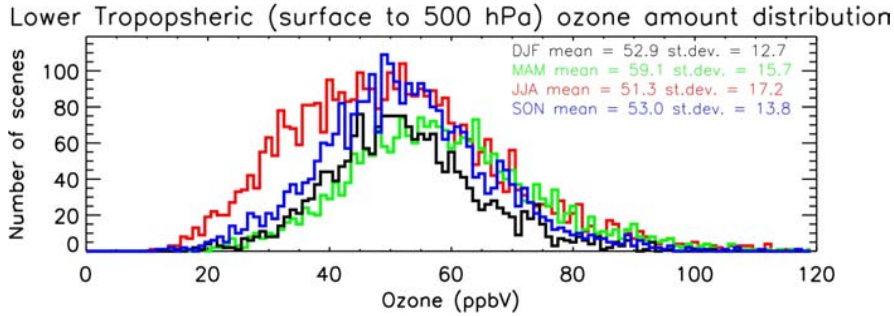


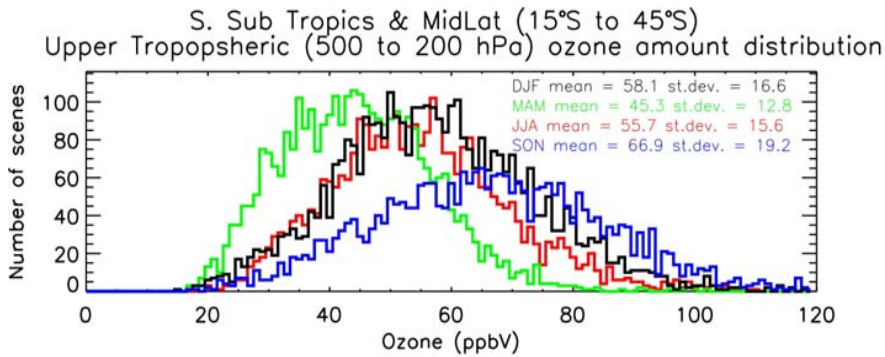


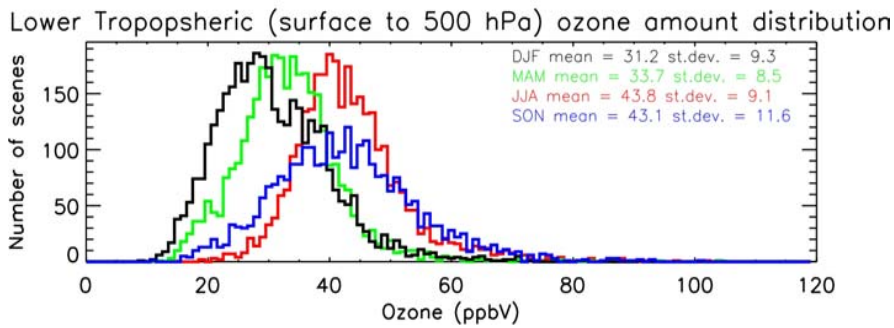
DJF 05-06 MAM 06
JJA 06 SON 06

Only clear-sky, ocean profiles are included.



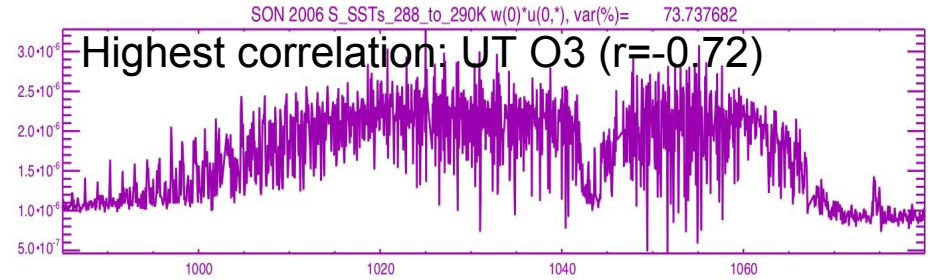


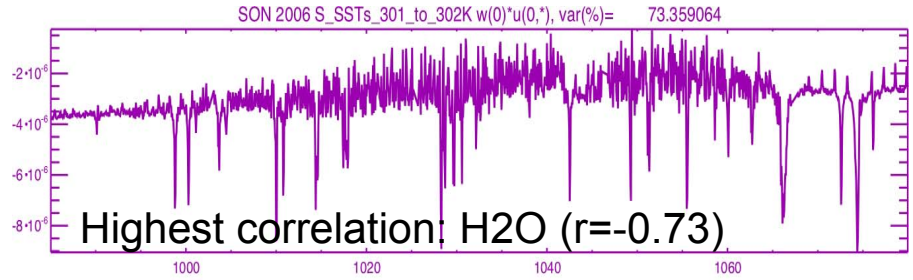


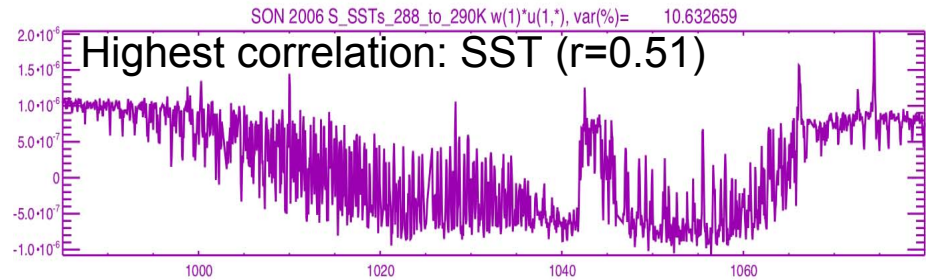


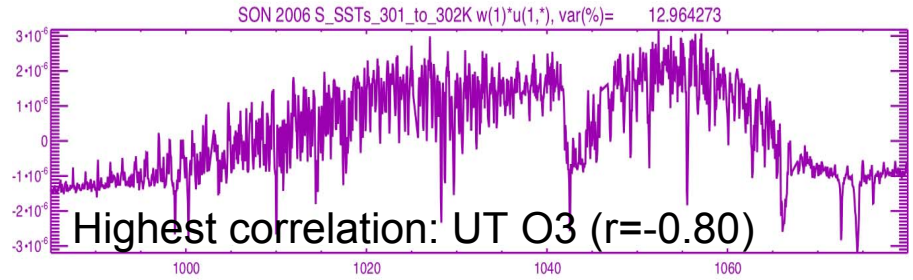
Bin TES measurements by Sea Surface Temperature (SST) to isolate variability in TOA flux due to Ozone and H2O

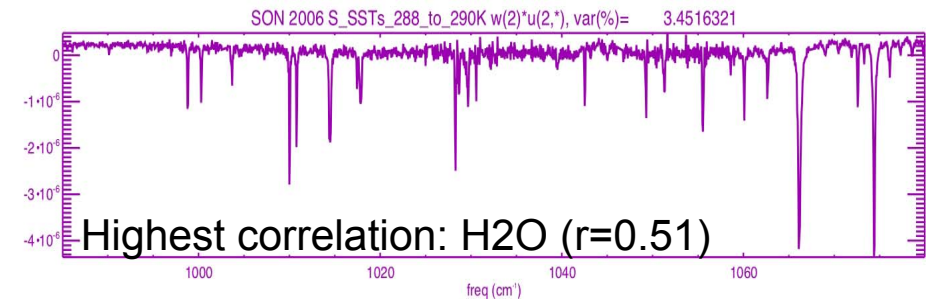
1st 3 Singular Vectors for SON 2006, cloud-free, ocean, SST bins
S. midlat [288K to 290K] and S. tropics [301K to 302K]

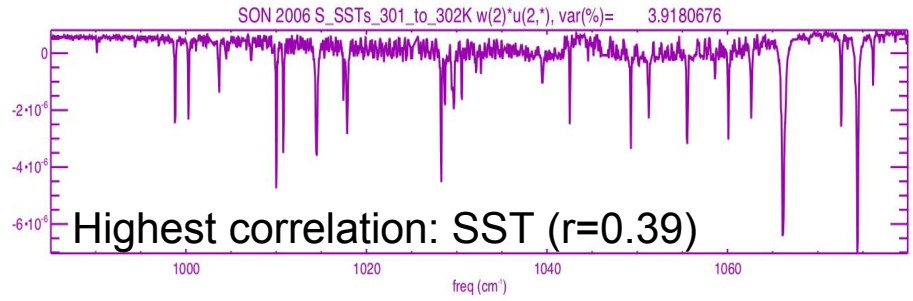


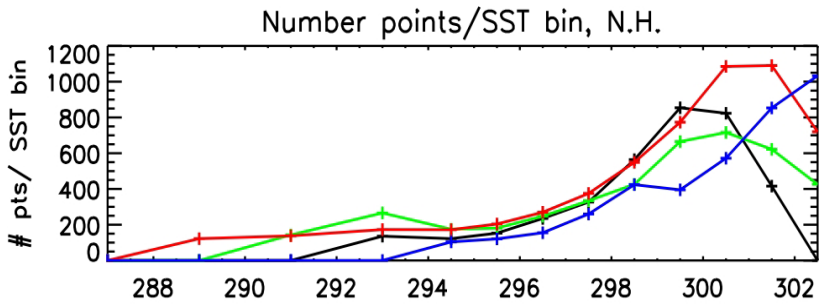


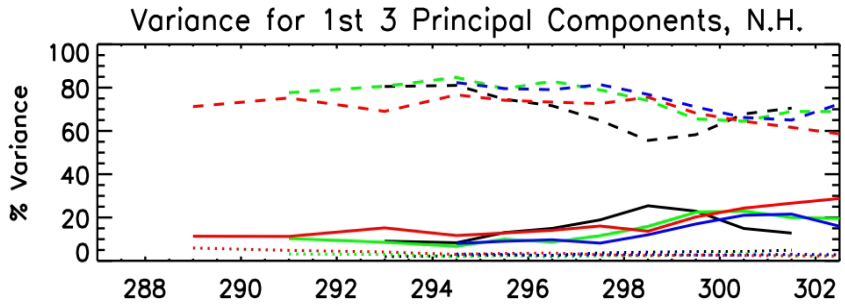


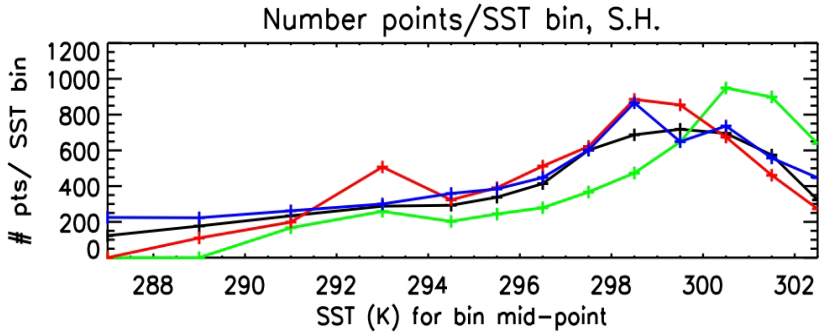


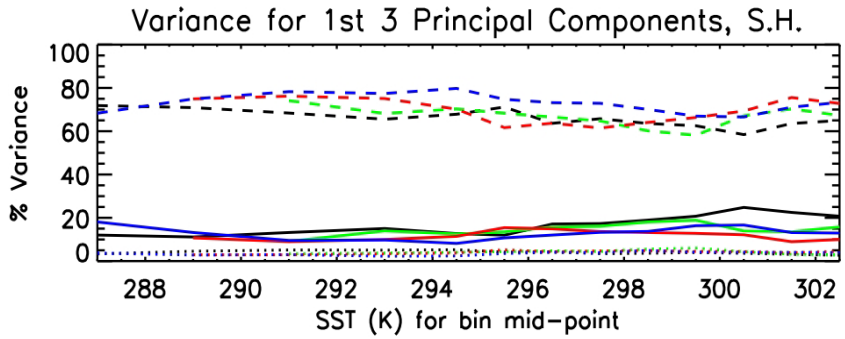





Number points/SST bin, N.H.
pts/ SST bin
0
200
400
600
800
1000
1200
288
290
292
294
296
298
300
302

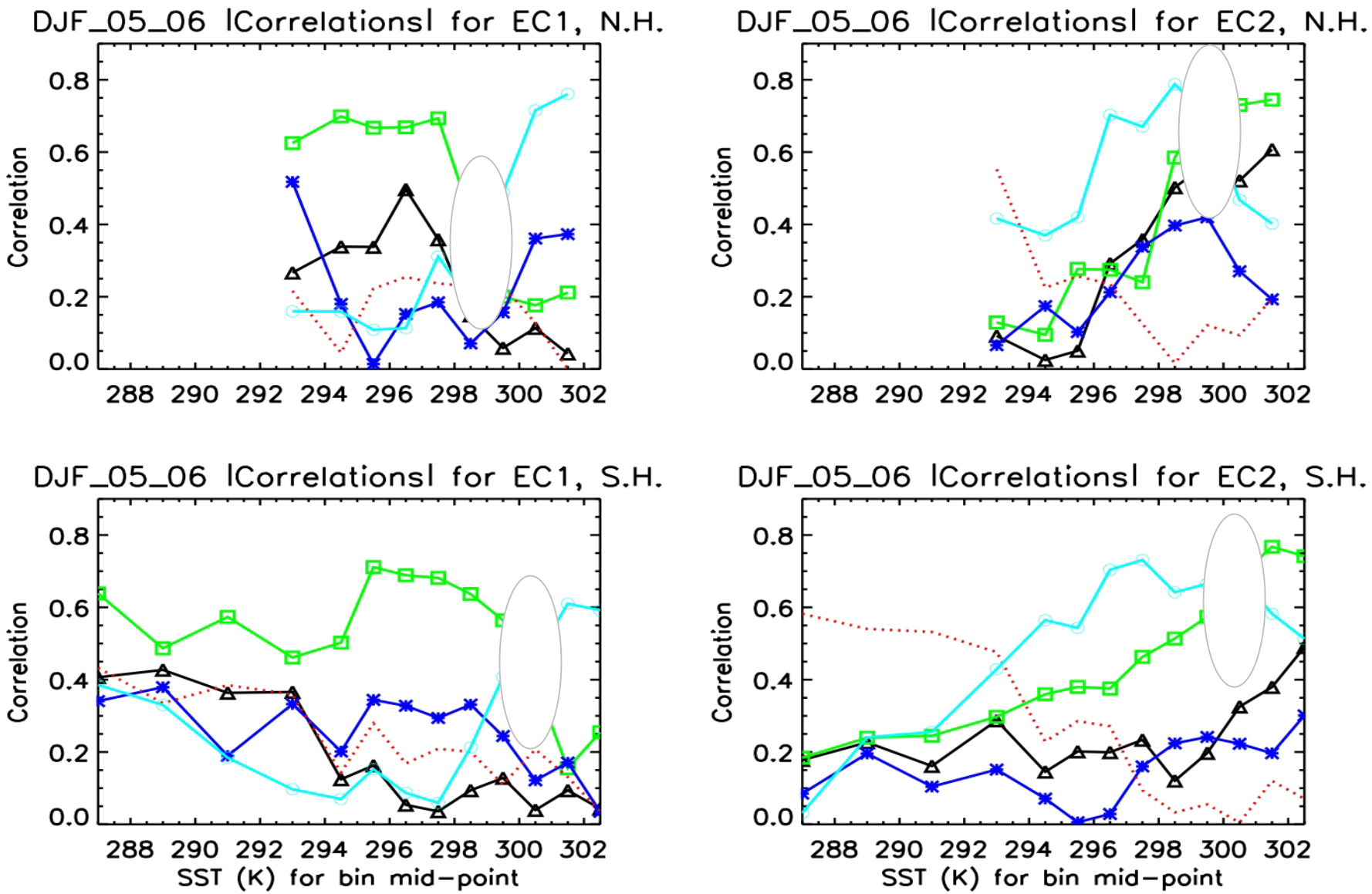

Variance for 1st 3 Principal Components, N.H.
% Variance
0
20
40
60
80
100
288
290
292
294
296
298
300
302

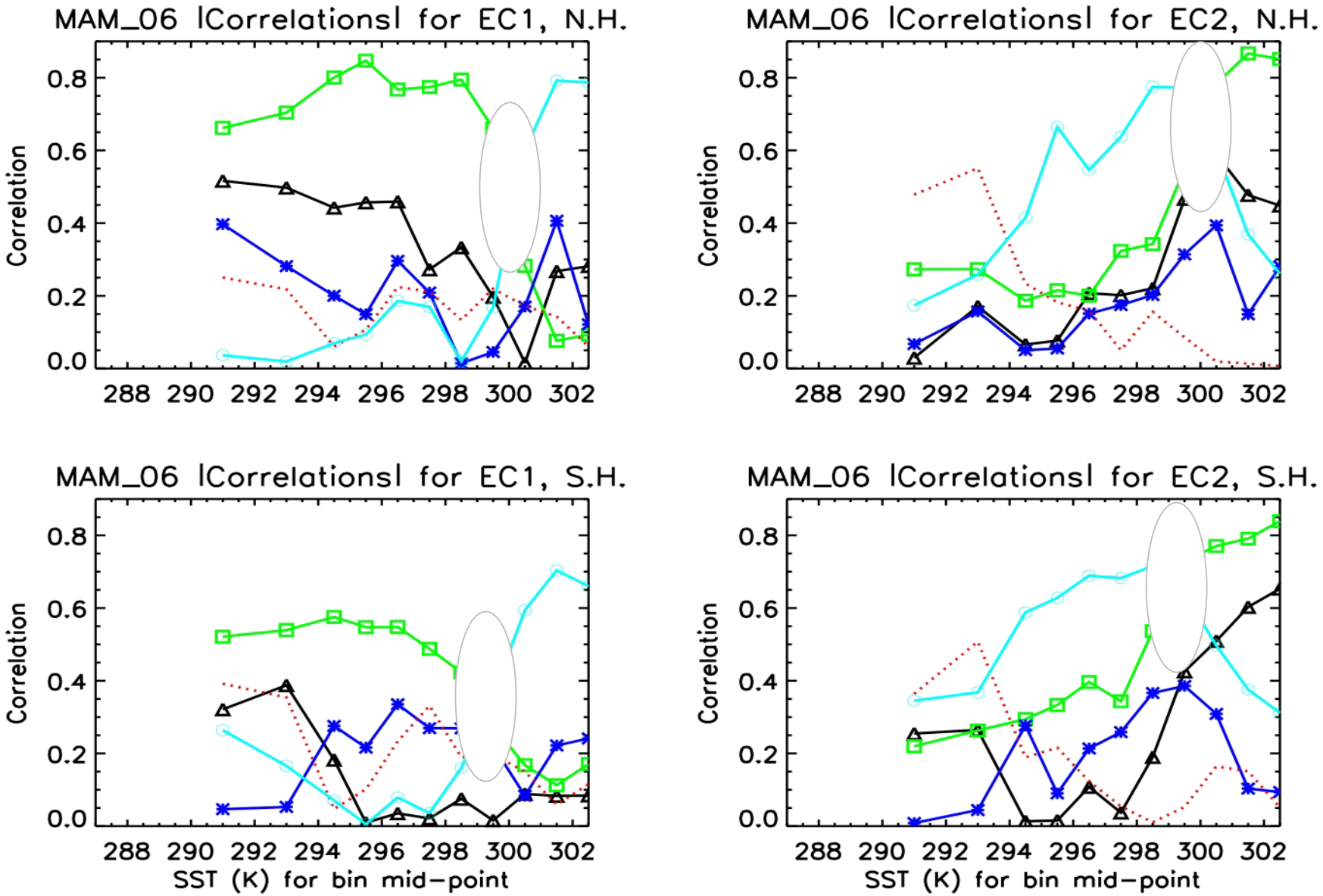

Number points/SST bin, S.H.
pts/ SST bin
0
200
400
600
800
1000
1200
288
290
292
294
296
298
300
302
SST (K) for bin mid-point

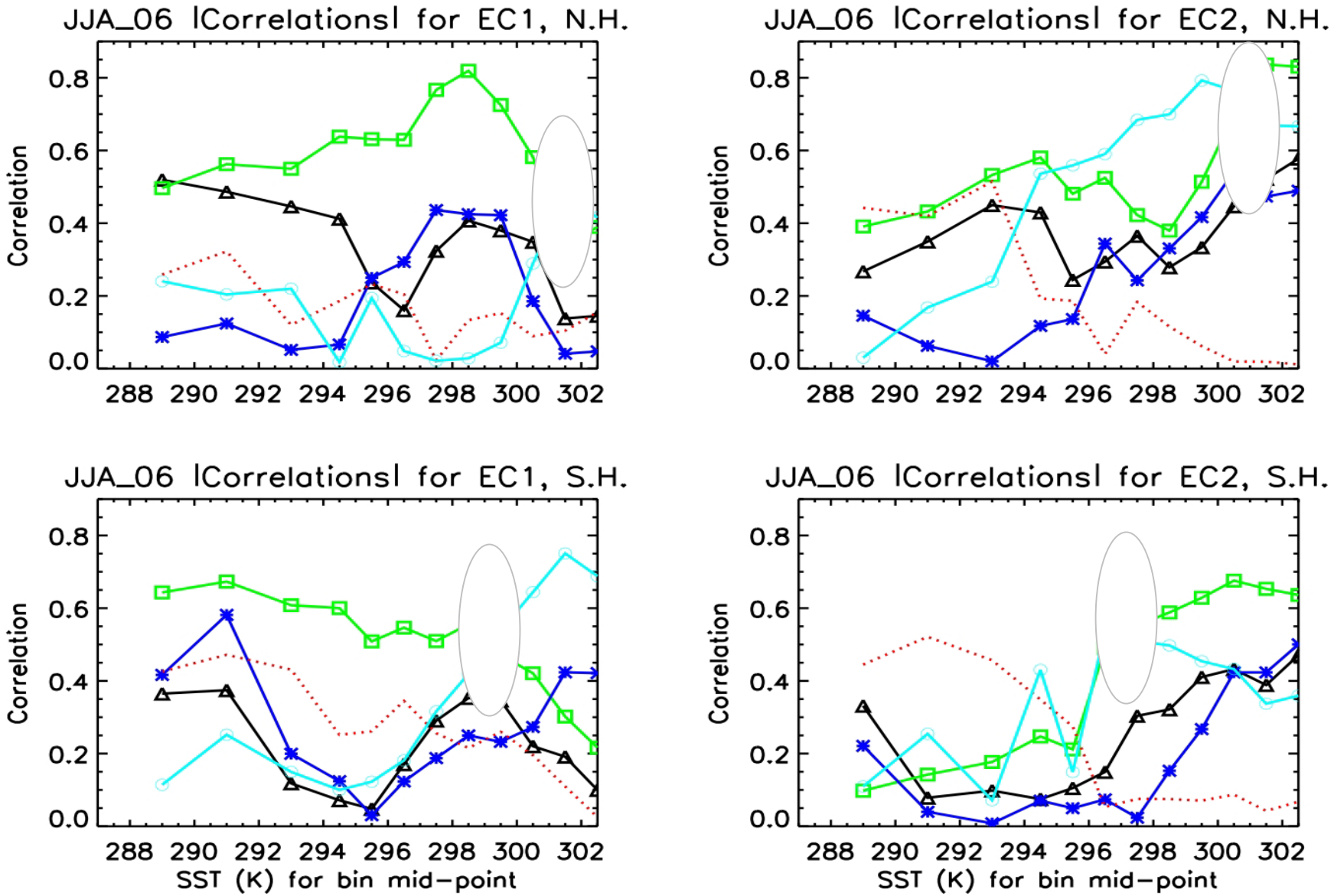

Variance for 1st 3 Principal Components, S.H.
% Variance
0
20
40
60
80
100
288
290
292
294
296
298
300
302
SST (K) for bin mid-point

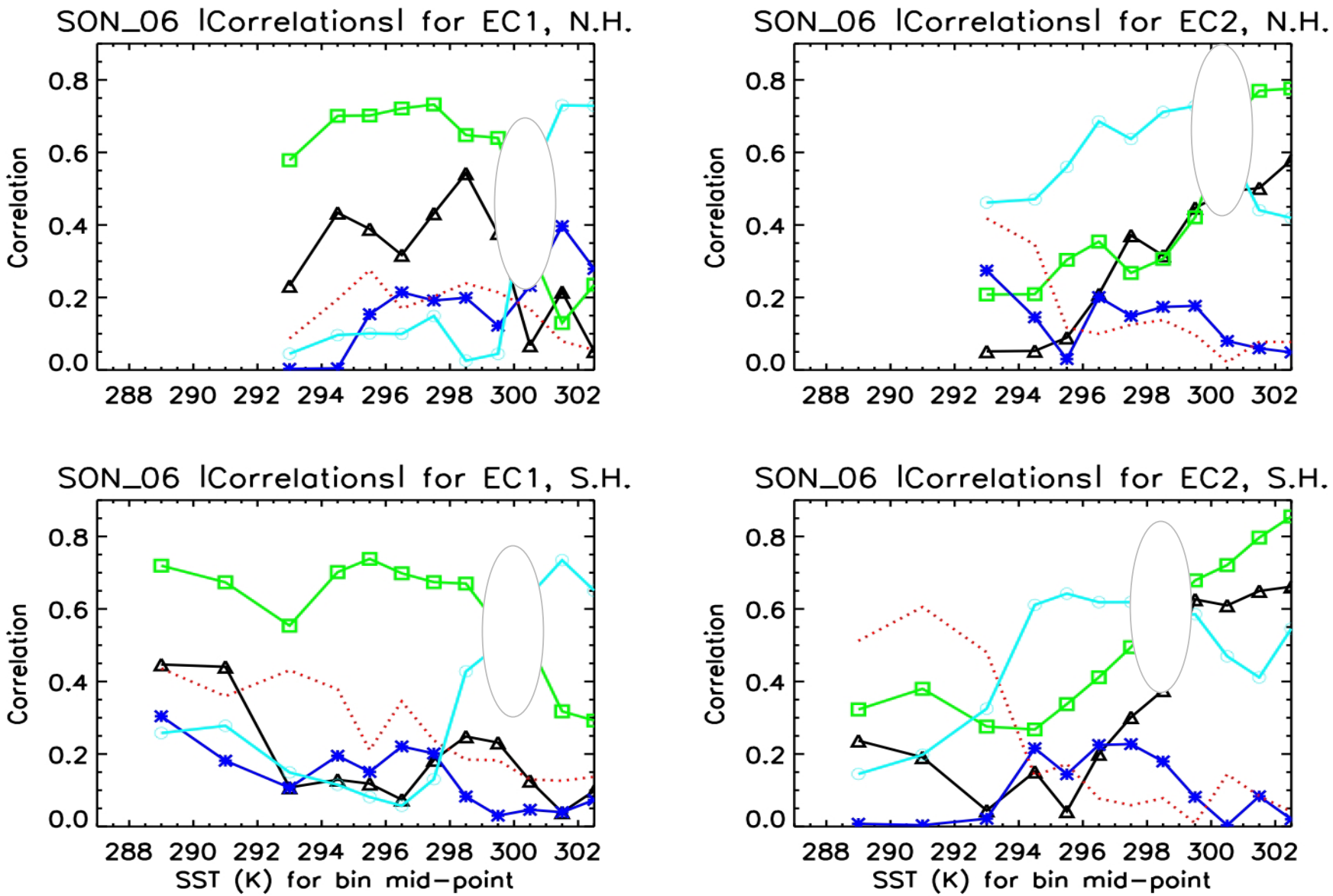

DJF 05-06
MAM 06
JJA 06
SON 06

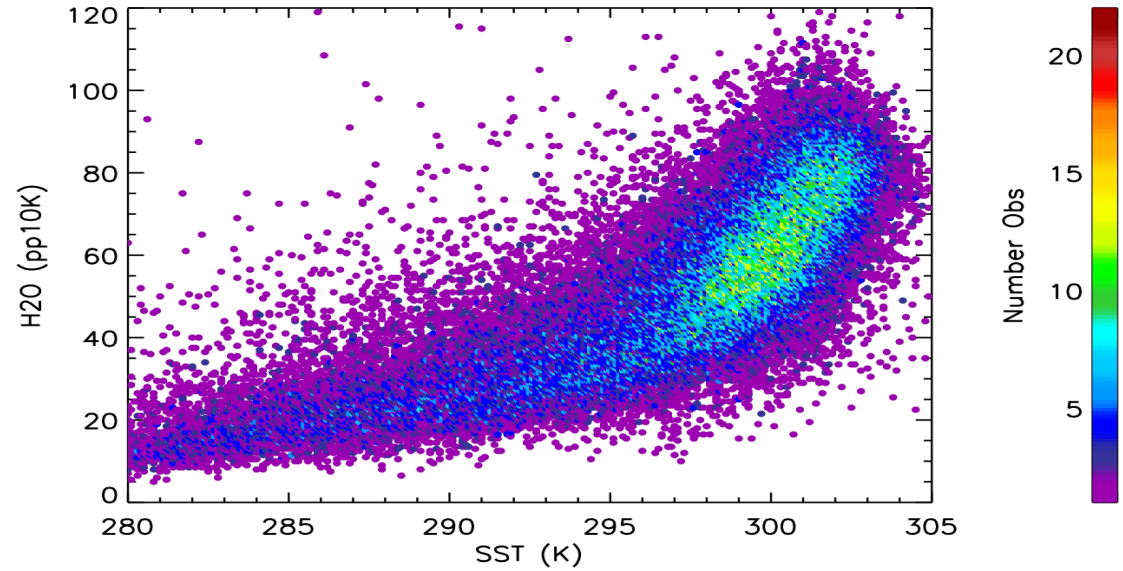

DJF 05-06
MAM 06
JJA 06
SON 06
PC1
PC2
PC3


DJF_05_06 |Correlations| for EC1, N.H.
DJF_05_06 |Correlations| for EC2, N.H.
DJF_05_06 |Correlations| for EC1, S.H.
DJF_05_06 |Correlations| for EC2, S.H.
Correlation
0.0
0.2
0.4
0.6
0.8
288 290 292 294 296 298 300 302
SST (K) for bin mid-point
triangle = LT O3
square = UT O3
asterisk = strat O3
circle = H2O (trop avg.)
..... = SST

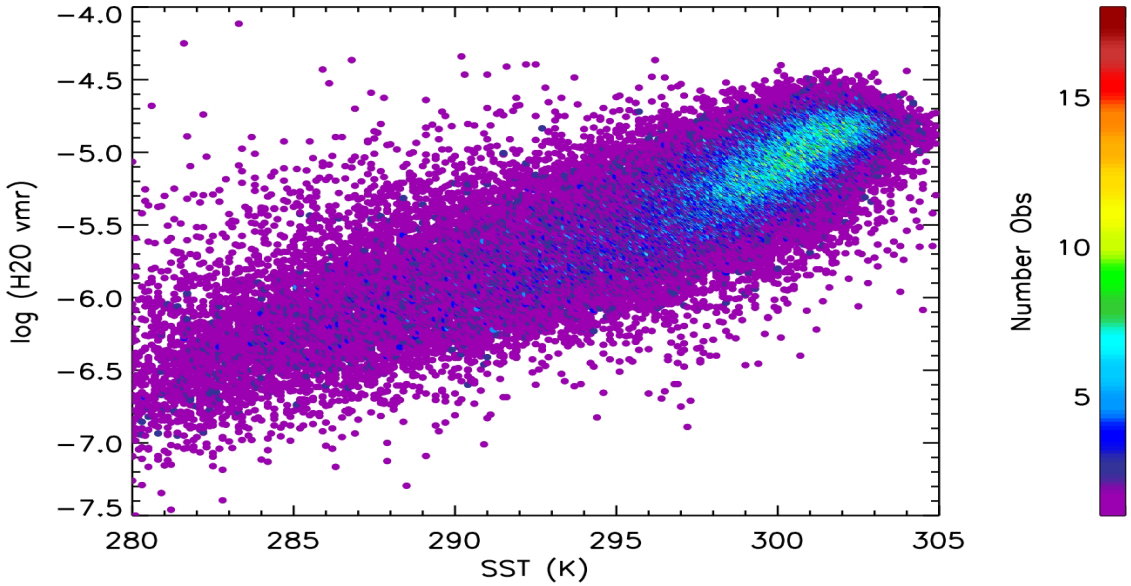

MAM_06 |Correlations| for EC1, N.H.
MAM_06 |Correlations| for EC2, N.H.
MAM_06 |Correlations| for EC1, S.H.
MAM_06 |Correlations| for EC2, S.H.
Correlation
0.0
0.2
0.4
0.6
0.8
288 290 292 294 296 298 300 302
SST (K) for bin mid-point
triangle = LT O3
square = UT O3
asterisk = strat O3
circle = H2O (trop avg.)
..... = SST


JJA_06 |Correlations| for EC1, N.H.
JJA_06 |Correlations| for EC2, N.H.
JJA_06 |Correlations| for EC1, S.H.
JJA_06 |Correlations| for EC2, S.H.
Correlation
0.0
0.2
0.4
0.6
0.8
288 290 292 294 296 298 300 302
SST (K) for bin mid-point
triangle = LT O3
square = UT O3
asterisk = strat O3
circle = H2O (trop avg.)
..... = SST


SON_06 |Correlations| for EC1, N.H.
SON_06 |Correlations| for EC2, N.H.
SON_06 |Correlations| for EC1, S.H.
SON_06 |Correlations| for EC2, S.H.
Correlation
0.0
0.2
0.4
0.6
0.8
288 290 292 294 296 298 300 302
SST (K) for bin mid-point
triangle = LT O3
square = UT O3
asterisk = strat O3
circle = H2O (trop avg.)
..... = SST



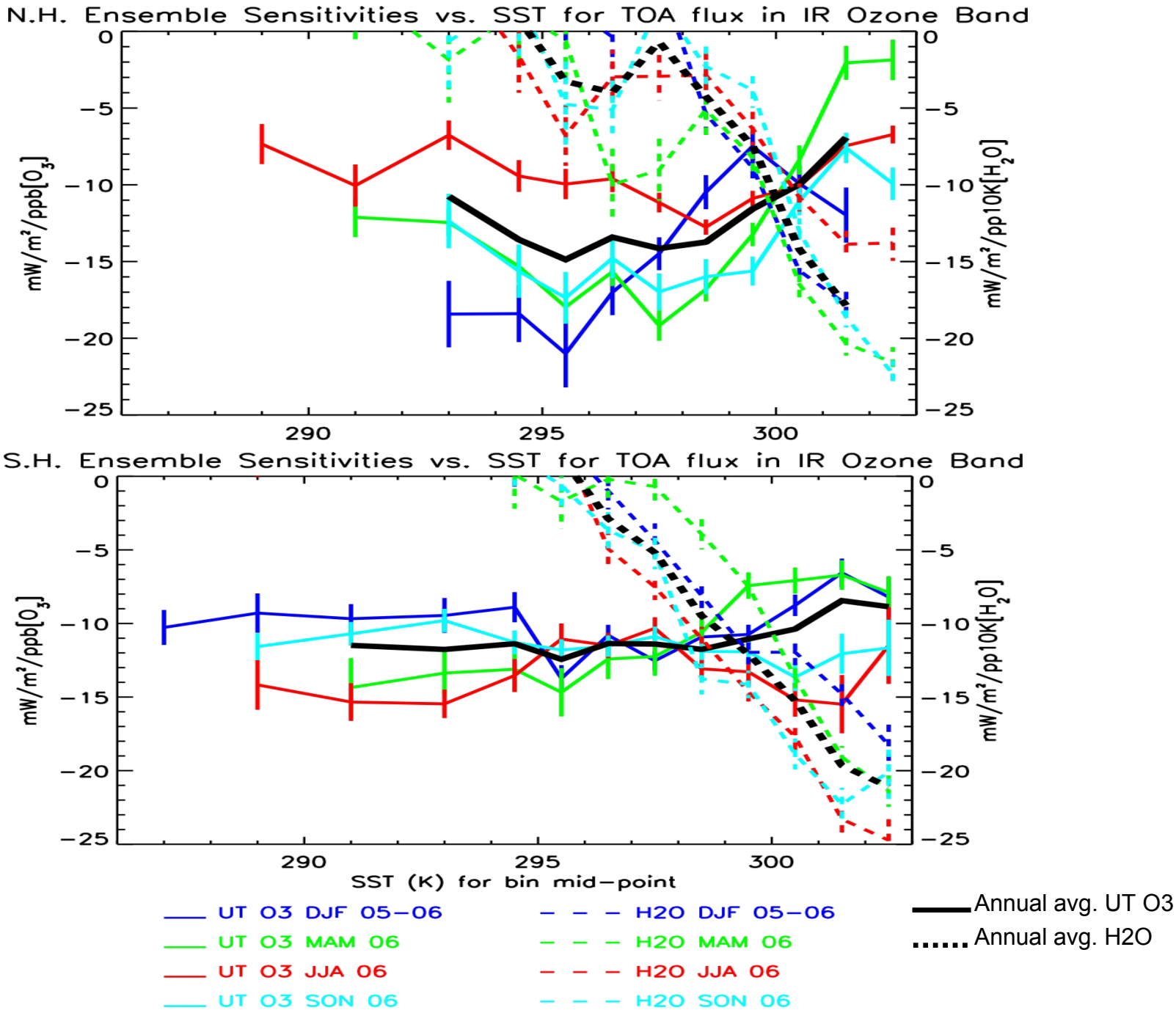
Avg. tropospheric (surf - 200 hPa) H2O vmr vs. SST(K)



Log H2O vmr vs. SST(K)

N. Hemis.

S. Hemis.



Linear fits of TOA flux (W/m^2) vs O_3 (pppV) for SST bin, N/S hemisphere ensembles, JJA_06